

**A UNIFIED LANDSCAPE:**  
**Reconnecting the Ala Wai Watershed to Ancient Waikīkī**

A D. ARCH PROJECT SUBMITTED TO THE GRADUATE DIVISION OF THE  
UNIVERSITY OF HAWAII AT MĀNOA IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF ARCHITECTURE

MAY 2017

By

Bea Clare Alveza Aglibot

D.Arch Committee:

Judith Stilgenbauer, Chairperson  
Daniele Spirandelli  
Mariana Boldu  
Joel Kurokawa

Keywords: Ala Wai, Waikīkī, ahupua'a, stream restoration, watershed, landscape identity

To mom and dad, for your unconditional love, encouragement, and support. There are thousands of words in this book and I could write more, but there will never be enough words to express my love, adoration, and gratitude for all that you have given and sacrificed for me. I love you both, forever.



To my committee, Judith, Daniele, Mariana, and Joel, for your guidance, dedication, and commitment. I am grateful for the knowledge that you have imparted with me.

To my 'architortured' friends, to my 750Girls, to Boo and Kykylani, for your friendship, for the laughs, and for making sure I stayed awake for the past seven years. I will miss this the most.

## ABSTRACT

A landscape's inherent characteristics—physical attributes, human activity, collective memory, and enduring symbols and lasting meanings—give it an identity. The landscape's identity is the uniqueness of a place. Water is sacred to the native Hawaiians. Water is said to “flow from the upland forests, down through the ahupua‘a, where it passes from the wao akua, the realm of the gods, to the wao kanaka, the realm of the man to sustain human life.” In Hawaii, water sculpts the landscape. In turn, the landscape sculpted the ancient Hawaiian culture and society. The Hawaiians structured their society to be in-sync with their natural environment because they understood that dependency on their surroundings. No one owned land in ancient Hawai‘i because they believed it all belonged to the gods. God’s land was sacred and was thus treated with respect. Reverence for the natural landscape created a commensalistic relationship between the natural environment and the human society.

However, with the arrival of Westerners in the late 1700s, the identity of the Hawaiian landscape changed. The foreigners introduced a false dichotomy between the built and natural environment and caused a shift in culture from a commensalistic mutuality with nature to a parasitic association with nature. The post-contact Hawaiian society eventually drifted away from the natural environment that their culture was initially based in. Now, the society sculpts the landscape themselves, cutting the land into pieces of marketable goods and controlling the water through hydromodification.

The landscape shifted from being wholly ko mau akua ‘āina (god’s land) to fragmented pieces of real property. It is important to bridge the disconnect between culture and nature by addressing the components of a landscape’s identity: the physical, the social, and the symbolic.

How can the inherent characteristics of the ancient ahupua‘a inform design interventions for Hawai‘i’s current water infrastructure so that it strengthens the landscape identity, reconnects the urban to the natural, and mitigates hydromodification?

## LIST OF FIGURES

- Figure 1: The Ala Wai Canal after torrential rains and a sewage spill.
- Figure 2: The island of O‘ahu covered in waterways.
- Figure 3: Characteristics that make up a landscape’s identity.
- Figure 4: Land owners of the Ala Wai Watershed.
- Figure 5: Duke Statue at the Waikīkī waterfront, a tangible element in the landscape.
- Figure 6: The Planter
- Figure 7: The changing coastline of Chatham Massachusetts.
- Figure 8: The Nile before and after flooding.
- Figure 9: A celebration on the waterfront.
- Figure 10: Cross Section Diagram of a Watershed.
- Figure 11: The layers of a rainforest.
- Figure 12: Kawainui Marsh
- Figure 13: Breakdown of ahupua‘a
- Figure 14: Ecological and human services within the watershed.
- Figure 15: Ecosystem services diagram
- Figure 16: Diagram of urban water infrastructure.
- Figure 17: Water and nutrient cycles in the rainforest.
- Figure 18: How wetlands work.
- Figure 19: The Hawaiian Islands.
- Figure 20: Orographic precipitation
- Figure 21: Freshwater sources on O‘ahu.
- Figure 22: Papa and Wakea
- Figure 23: Haloa
- Figure 24: Landscape identity in relation to the creation story.
- Figure 25: Conceptual ahupua‘a.
- Figure 26: The water as a parti through an ahupua‘a.
- Figure 27 Ancient Waikīkī overlayed on the present day urbanized O‘ahu.  
Ancient waterways, known locations agricultural plots c. 1890s.
- Figure 28: Taro field from McCully Street looking toward Laē‘ahi.
- Figure 29: 1929 Aerial view of the Waikīkī coast with Laē‘ahi in the background.
- Figure 30: Ancient Waikīkī flora.
- Figure 31: An 1893 map showing the expanse of agricultural food production within the coast and the midlands.
- Figure 32 King Kamehameha V’s residence in Helumoa.
- Figure 33: The Moana Hotel, the First Lady of Waikīkī.
- Figure 34: Construction of the Ala Wai Canal.

Figure 35: Horse race track at the park.

Figure 36: Postcard of Kapi'olani Park with water features.

Figure 37: Subak irrigation by Balinese farming communities.

Figure 38: Cordillera rice terraces.

Figure 39: Plan of the Mānoa Stream Park

Figure 40: Conceptual plan for the Ala Wai Golf Course Detention System.

Figure 41: USACE plan for the Ala Wai Watershed.

Figure 42: Kāne and Kanaloa

Figure 43: Layout of loi in Kānewai

Figure 44: Mānowai

Figure 45: Po'owai

Figure 46: 'Auwai

Figure 47: Makawai

Figure 48: Diagram of linking patches of nature reserves across a landscape.

Figure 49: Aerial view of gradually sloping embankments.

Figure 50: Sidwell Friends Constructed Wetland Plan

Figure 51: Section of the constructed wetland.

Figure 52: Palettes

Figure 53: Cells consisting of seasonal vegetation.

Figure 54: Photos

Figure 55: Photo

Figure 56: Plan of Cheonggyecheon Stream

Figure 57: Landscape identity

Figure 58: Design approach in relation to landscape identity

Figure 59: Types of LID strategies to mitigate stormwater runoff.

Figure 60: Planting for Manoa Valley District Park

Figure 61: Native plants for Kapi'olani Regional Park

Figure 62: Native plants for constructed wetlands water remediation.

Figure 63: Ala Wai landscape identity

# TABLE OF CONTENTS

DEDICATION.....	ii
ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	iv
LIST OF FIGURES.....	v
I INTRODUCTION AND RESEARCH FOCUS.....	1
1.1 PURPOSE OF THE PROJECT	
1.2 RESEARCH QUESTION	
1.3 STUDY AREA	
1.4 ORGANIZATION OF THE PROJECT	
1.5 SCOPE OF THE PROJECT	
II RESEARCH PORTION.....	14
2.1 LANDSCAPE AND THE GENIUS LOCI	
2.2 WATER	
2.3 THE EDGE AND THE WATERFRONT	
2.4 WATERSHEDS	
2.5 HYDROMODIFICATION	
2.6 LANDSCAPE INFRASTRUCTURE	
III SITE.....	65
3.1 PHYSICAL	
3.2 PEOPLE & MYTHS	
3.3 AHUPUA'A	
3.4 RISE OF WESTERN AGRICULTURE	
3.5 THE OLD WAIKĪKĪ	
3.6 THE ALA WAI WATERSHED	

IV	PRECEDENTS.....	100
4.1	SIMILAR INDIGENOUS WATERSHED MODELS	
4.2	LOCAL PLANS OF ACTION	
4.3	PU'UHONUA – PLACES OF REFUGE	
4.4	LANDSCAPE INFRASTRUCTURE	
V	QUALITIES OF A UNITED LANDSCAPE.....	128
5.1	PROBLEM STATEMENT	
5.2	WATER MEMORY AND LANDSCAPE IDENTITY	
5.3	WATERSHED MODEL AND MANAGEMENT	
5.4	APPLICATIONS OF LANDSCAPE INFRASTRUCTURE	
VI	DESIGN APPROACH AND APPLICATION.....	140
6.1	SITE ANALYSES	
6.2	ALA WAI WATERSHED	
6.3	MĀNOA VALLEY REGIONAL PARK	
6.4	KAIMUKI HIGH SCHOOL	
6.5	KAPI'OLANI REGIONAL PARK	
VII	CONCLUSION.....	195
VIII	BIBLIOGRAPHY.....	203

# **I INTRODUCTION AND RESEARCH FOCUS**

## 1.1 PURPOSE OF THE PROJECT

The research is focused on establishing a rationale in connecting the existing urbanized Ala Wai Watershed with the ancient Waikīkī ahupua‘a through the design of landscape infrastructure informed by the inherent characteristics of the place. While it is impossible to return the Ala Wai Watershed to the pristine state it was prior to Western contact, it is necessary to reintroduce time-tested watershed concepts from the ancient Waikīkī landscape into the existing urban environment.

The purpose of the project is to explore the role of landscape, water, and identity in mitigating the adverse physical, social, and symbolic effects of hydromodification in the Ala Wai Watershed landscape. The project seeks to propose conceptual design interventions in lieu or alongside the existing tentative engineering proposals for the current watershed management system in the Ala Wai Watershed. The interventions proposed in this dissertation address physical, social, and symbolic problems at the extent of the conceptual and are not meant to be technical solutions to hydromodification.

The premise for this dissertation stem from these assumptions:

- There is a physical and cultural disconnect between the urban and natural environment.
- Water is the backbone of Hawai‘i’s urban and natural environment and good water quality depends on a closed-loop system.
- The Ala Wai Watershed’s urban framework is vulnerable to disasters.

The ancient Hawaiians had a spiritual and somatic connection with the natural environment. They began as seafarers who navigated across the Pacific Ocean from Kahiki (foreign land) to find new homes.<sup>1</sup> They settled the landscape of Hawai‘i with the understanding that water is life, for they navigated the deep ocean through their bodies and they were skilled agriculturists and fishers.<sup>2</sup> Just as water sculpts the landscape, the landscape and their collective memory of water sculpted the Hawaiian culture and society. They created

---

<sup>1</sup> George Kanahale, *Waikiki 100 BC to 1990 AD: An Untold Story* (Honolulu: Queen Emma Foundation, 1995), 11.

<sup>2</sup> Ibid., 12.



the unique ahupua‘a management model to manifest their memories of water and formed symbols with meanings like mauka and makai and rituals like the kapu. They also keenly observed the natural environment. Individuals had a thorough knowledge base and inventory of the ahupua‘a’s physical components and spiritual associations.

Water was the backbone of the natural and urban environment. Water was said to “flow from the upland forests, down through the ahupua‘a, it passed from the wao akua, the realm of the gods, to the wao kanaka, the realm of the man, where it sustained human life.”<sup>3</sup> The ahupua‘a had three ecological zones that were naturally organized by the network of streams and bodies of water: the wao akua (uplands) rainforest, the wao kanaka (midlands) agriculture fields and settlement, and kaha kai (coastal land) marshes and aquaculture lands. The wao akua and the kaha kai functioned to filter the water in its path to the human settlements and its return to the akua (gods). The human settlements in the wao kanaka also prioritized the quality of water that flows into the kaha kai. Today, the wao akua is protected as part of the Conservation District, the wao kanaka is urbanized and the kaha kai is missing (similarly in the quote), leaving a hole in the water cycle.

Figure 1: The Ala Wai Canal after torrential rains and a sewage spill.  
Source: Cory Lum<sup>4</sup>

---

<sup>3</sup> *Last Stand: The Vanishing Hawaiian Forest* (Honolulu, HI: Nature Conservancy of Hawai‘i, 2003), 7, 10.

<sup>4</sup> Cory Lum, Water in the Ala Wai Canal turned brown after heavy rains last week. In a major flood, the canal would overflow into the heart of Waikiki., digital image, Civil Beat, September 1, 2015, accessed December 10, 2016, <http://www.civilbeat.org/2015/09/ala-wai-canal-flood-control-the-high-cost-of-protecting-waikiki/>.

The Ala Wai Watershed's urban context is vulnerable to disasters. The Ala Wai Watershed's aging and inadequate infrastructure cannot handle small failures like water-main breaks and several highly visible catastrophic collapses like sewage spills. A 100-year flood would destroy more than 3000 structures and cost the state \$318 million in structural damages alone.<sup>5</sup> The U.S. Army Corps of Engineers is tentatively proposing the National Economic Development (NED) Plan, a series of flood risk management measures, one of which is the erection of 4-foot flood walls on both sides of the Ala Wai Canal and the other is building debris and detention basins within the uplands Conservation District.<sup>6</sup> However, these measures do not contribute to the landscape's identity, do not function to reconnect the natural and urban environment, minimally address water quality, and employ the very same traditional "hard" infrastructures that modified much of the streams and cause several of the problems.

Culture, as defined by Michael Weinstock, is "transmitting social and ecologically contextualized information down through the generations...each generation is bound into society and culture is how they contribute to it [society]."<sup>7</sup> The conveying of information in society through the generations was broken because of the pestilence that decimated much of the native Hawaiian population in the early 1800s. While the indigenous knowledge is forgotten, the ideas of stewardship and accountability can be continued today through best management practices in today's local level society: the community, in the neighborhood, and in the home.

The transmittal of indigenous watershed management knowledge was also lost with the extinction of the ahupua'a, after the pestilence. To remedy this ecologic disconnect, the concepts from the Waikiki landscape that need to be physically reintroduced into the Ala Wai Watershed's infrastructure are the structure and functions of these three ecological zones. In Hawai'i's current watershed management system, attention has turned to the value in rethinking outdated, and sometimes, misapplied man-made infrastructural systems because of small failures like water-main breaks and several highly visible catastrophic collapses like sewage spills. The use of "hard" traditional engineering approaches seems to be the cause of

---

<sup>5</sup> Army Corps of Engineers, *Ala Wai Canal Project, Oahu, Hawai'i Feasibility Study with Integrated Environmental Impact Statement*, by United States Army Corps of Engineers (USACE) (2015), 7.

<sup>6</sup> Ibid., 215.

<sup>7</sup> Michael Weinstock, *The Architecture of Emergence: The Evolution of Form in Nature and Civilization* (Chichester, U.K.: Wiley, 2010), 19.

hydromodification in any watershed scenario. But at the same time, while there is advocacy for emerging flexible, responsive “soft” systems,<sup>8</sup> they are still mostly untested.

The landscape of Hawai‘i consists entirely of compact watersheds and they are unlike anywhere else in the world. While we must employ prevalent, typical watershed management practices and new technologies, we must also look to past watershed management models that have worked, distinctly, for the Hawaiian landscape. The ahupua‘a model was extremely successful in maintaining a high-quality watershed while still providing the necessary ecosystem services to the Hawaiian society. Ideally, the future watershed management model for Hawai‘i should combine applicable concepts from the ahupua‘a model with emergent systems that promote “soft” infrastructure that mimic or enhance that of Hawai‘i’s indigenous watershed management model.

Figure 2: The island of O‘ahu covered in waterways.  
Source: By Author

---

<sup>8</sup> Stephanie Carlisle and Nicholas Pevzner, "Introduction: Rethinking Infrastructure," Scenario Journal, October 24, 2015, Emerging Conversations, accessed November 11, 2016, [http://scenariojournal.com/article/introduction\\_rethinking\\_infrastructure/](http://scenariojournal.com/article/introduction_rethinking_infrastructure/).

While the Ala Wai Watershed will never return to its pre-Western state, it is necessary to convey the past layers from which the ancient Waikīkī ahupua‘a evolved, beginning with its natural conception as an upland rainforest and coastal marsh, its eventual cultivation as agricultural lands, to its eventual identity as the seat of power in the Hawaiian Islands, and to its transition into an urban resort for the transients into the design of the urban framework. This collective memory, alongside reintegrating time-tested ahupua‘a functions, should be evident in Waikīkī’s rebranding as the Ala Wai Watershed.

## 1.2 RESEARCH QUESTION

A landscape's inherent characteristics—physical attributes, collective memories, human activity, and enduring symbols and lasting meanings—give it an identity, the uniqueness of a place. These characteristics can also serve to mitigating the adverse physical, social, and symbolic effects of hydromodification and disconnect from nature. The Ala Wai Watershed must unify its past and present identities of landscape through form and strengthen it through function.

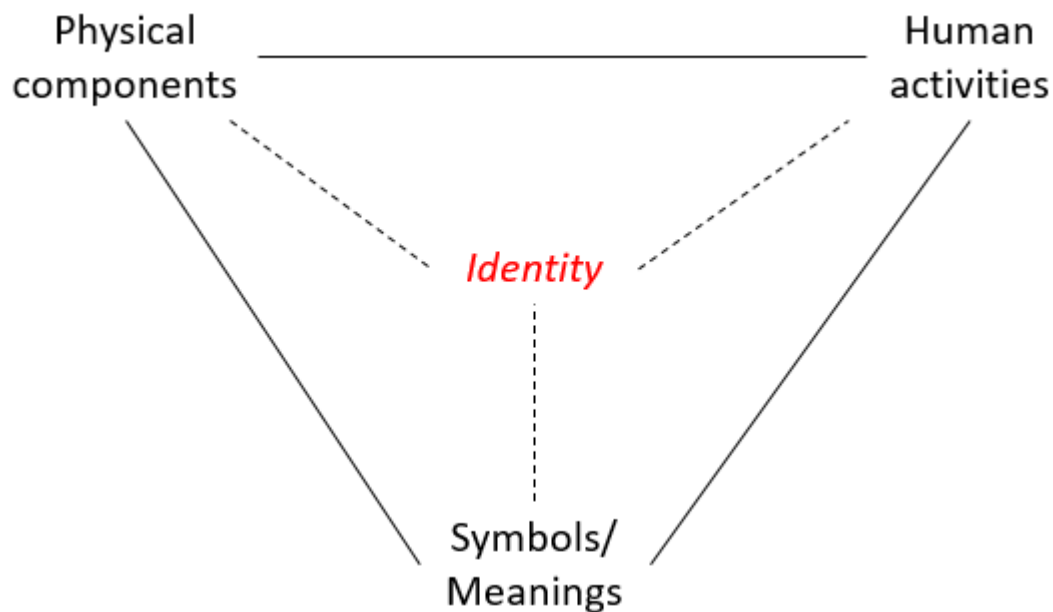


Figure 3: Characteristics that make up a landscape's identity.  
Source: By Author

**Therefore, how can the inherent characteristics of the ancient Waikī ahupua‘a inform multidisciplinary design interventions for the Ala Wai Watershed’s infrastructure so that it strengthens the landscape identity, reconnects the urban to the natural, and mitigates hydromodification?**

Water sculpts the landscape. The landscape and the Hawaiians’ collective memory of water sculpted their culture and society. No one owned land because they believed everything belonged to the gods, and they were guests. The Hawaiians structured their society to be in-sync with their natural environment because they understood their dependency on their

surroundings. Even in their design of irrigation infrastructure, they didn't alter the water's path or flow.

Today, humans sculpt the landscape and control the water. All three major streams that empty into the Ala Wai Canal have been modified and only function to carry storm water from the urbanized areas into the canal, and out into the ocean. Ownership of the Ala Wai Watershed is divided among many entities and individuals. Management and maintenance of the watershed is therefore “fragmented amongst several government agencies and private land owners”<sup>9</sup> instead of a singular entity with a hierarchal approach that starts at the island level.

Figure 4: Land owners of the Ala Wai Watershed.  
Source: By Author

The current urban framework retards the relationship that society and culture should have with nature in three ways. First, it homogenized the landscape's physical characteristics

---

<sup>9</sup> Townscape, Inc. and Eugene Dashiell, *Ala Wai Watershed Analysis Final Report*, report (2003), 27.

from the unique mauka to makai ahupua‘a landscape to a Western urban landscape that didn’t consider its immediate environment. The physical shift created a false dichotomy between the built and natural environment, and paved the way for hydromodification. Second, it caused a shift in human activity from a commensalistic mutuality to a parasitic association. The sociologic shift suppressed the indigenous collective memory, and with it, the understanding of human dependence on natural ecosystems and the services they provide. Third, it introduced a new, foreign set of meanings of landscape with which the ancients’ values didn’t correspond to, but the foreigners’ values did. Ali‘i (chiefs), maka‘āinana (literally, eyes of the land) and capitalist were definitions of who people were, and the landscape is transformed distinctly for each one, indicative of their self-definitions.<sup>10</sup> The symbolic shift led to the Māhele, which challenged and eventually changed societal views of landscape. The landscape shifted from being wholly ko mau akua ‘āina (god’s land) to fragmented pieces of real property. It is important to bridge the disconnect between culture and nature by addressing the components of a landscape’s identity: the physical, the social, and the symbolic.

It is impossible to return the Ala Wai Watershed to its ancient, pristine state. However, this research hopes to rectify the tear in landscape identity between the ancient Waikīkī ahupua‘a and Ala Wai Watershed by re-accessing the collective memory of indigenous knowledge, and applying it to our current urban framework. The research objective is to address landscape identity, architectural form, and infrastructure alternatives for the Ala Wai Watershed at the extent of the conceptual and are not meant to be technical solutions to hydromodification. The design solution aims to embed the ahupua‘a model, Hawai‘i’s indigenous watershed management model, back into the current watershed to preserve the Ala Wai Watershed physically, socially, and symbolically for future generations.

---

<sup>10</sup> Thomas Greider and Lorraine Garkovitch, "Landscapes: The Social Construction of Nature and the Environment," *Rural Sociology*, Spring 1994, 59, no. 1, pg. #, accessed December 10, 2016, [http://www.issw.ch/info/mitarbeitende/hunziker/teaching/download\\_mat/Greider\\_Garkovitch\\_1994.pdf](http://www.issw.ch/info/mitarbeitende/hunziker/teaching/download_mat/Greider_Garkovitch_1994.pdf).

### 1.3 STUDY AREA

There are two images of the watershed: the ancient Waikīkī Ahupua‘a and the Ala Wai Watershed. To draw a problem, it is important to analyze the physical, social, and symbolic differences between the two images of the same site. One image is picturesque and fertile in the descriptions of the first foreigners who saw Waikīkī. The second image is urbanized and unsustainable, as it is today.

#### Ancient Waikīkī Ahupua‘a

The Waikīkī ahupua‘a is located on the south side of the Island of O‘ahu, Hawai‘i. Prior to the 1800s, the ahupua‘a encompassed the area extending from Kou (Honolulu) to Maunalua (Hawai‘i Kai). It was bordered by the Papakōlea ridge, through the peak of Konahuanui, along the crest of the Ko‘olau Ridge that it shares with the Kailua and the Waimānalo ahupua‘a on the Windward side, to Maunalua. Its coastal boundaries are not precise because of the ephemeral nature of marshlands. The Waikīkī ahupua‘a was hypothesized to have been settled by the earlier Windward settlers who migrated to the Leeward side of O‘ahu to establish more communities.

According to Kanahele, Waikīkī was the “next best place”<sup>11</sup> in the ancients’ search for a similar landscape condition as their Kailua settlements<sup>12</sup>—good soil, tillable terrain, adequate rainfall, networks of streams, forested uplands, calm shores, rich marine life, and a protective outer reef.<sup>13</sup> George Vancouver described his Waikīkī surroundings in 1792 as “*pleasingly interspersed with deep, though not extensive valleys; which, with the plains near the sea-side, presented a high degree of cultivation and fertility.*”<sup>14</sup> Within 50 years of Captain Cook’s arrival in 1778, Waikīkī’s ahupua‘a became a “graveyard of deserted taro patches and homes and dead planters.”<sup>15</sup>

---

<sup>11</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 14.

<sup>12</sup> Ibid., 14.

<sup>13</sup> Ibid., 12.

<sup>14</sup> Ibid., 82.

<sup>15</sup> Ibid., 103.



## **Ala Wai Watershed**

Changes within the Waikīkī watershed began with the Māhele in 1848, which allowed foreigners to purchase land. The landscape transformed into a home for the aliʻi and some foreigners.<sup>16</sup> Succeeding the overthrow of the monarchy and Hawaiʻi's annexation to the United States in 1898, Waikīkī transitioned into the urban resort we know today. The ahupuaʻa of Waikīkī is presently called the Ala Wai Watershed. The 19-square-mile watershed encompasses extends from the ridge of the Koʻolau Mountains to Māmala Bay.<sup>17</sup>

The upper part of the Ala Wai Watershed is zoned as a protected subzone of the Honolulu Watershed Forest Reserve in the Conservation District.<sup>18</sup> The valleys and most of the coastal plains are urbanized and account for 15 percent of the island's population.<sup>19</sup> Makiki, Mānoa, and Pālolo streams flow into the Ala Wai Canal, a 2-mile-long canal constructed in the 1920s that created the Waikīkī District. The canal is frequently used by tourists and residents for walking, running, biking, fishing, and canoeing despite sanitary issues associated with surface water quality and sedimentation.

## **Comparison**

The old Waikīkī ahupuaʻa was a healthy watershed that prospered because the ancient Hawaiians had a filial relationship with their landscape. The Ala Wai Watershed is the unhealthy successor. However, based on the diverse and high-quality recreational attributes of the water system, the Hawaiʻi Cooperative Park Service Unit identifies the overall Ala Wai Canal System, as a regionally outstanding recreational resource. The watershed also continues to serve as a home to a big population, albeit a size that the watershed cannot independently support. The problem is that the watershed is degraded to the point that the ecosystem services it provides are limited to inferior storm water drainage and at-health-risk recreation. The water network does not provide potable water, food resource, and wildlife habitat among other services that a healthy watershed should be providing.

---

<sup>16</sup> Ibid., 114-115, 134.

<sup>17</sup> AlaWaiChallenge.org, "Resources," Ala Wai Student Design Challenge, Area Information, accessed December 2, 2016, <http://www.alawaichallenge.org/resources.html>.

<sup>18</sup> State of Hawaiʻi Department of Land and Natural Resources (DLNR), "State of Hawaiʻi Conservation District Subzone - Island of Oahu," map, [Dlnr.Hawaii.gov](http://dlnr.Hawaii.gov), November 2012, accessed December 1, 2016, [http://dlnr.Hawaii.gov/occl/files/2013/08/oahu\\_consv\\_subz2012\\_1101.pdf](http://dlnr.Hawaii.gov/occl/files/2013/08/oahu_consv_subz2012_1101.pdf).

<sup>19</sup> AlaWaiChallenge.org, Area Information.

## 1.4 ORGANIZATION OF THE PROJECT

In order to develop a design that fuses landscape identity, urban and natural reconnection, and landscape infrastructure into a formal intervention, it is first necessary to understand the scope, limitations, and organization of this project. The design research is divided into two portions: Parts I through IV review theories, histories, and precedent studies. Parts V to VII state guiding principles, design interventions, and conclusions.

First, the dissertation reviews theories on landscape and the *genius loci*; water; the edge and the waterfront; the ahupua‘a and typical watershed models; hydromodification; and landscape infrastructure. Second, the history of Hawai‘i and the Ala Wai Watershed with emphasis on select sites illustrates the past and present states of the landscape in terms of its physical characteristics, its social makeup, and its intangible attributes. Third, the study presents precedents of similar indigenous watershed management models, examples of ahupua‘a concepts being practiced today, and precedents of landscape infrastructures. Part V states the premise for this thesis, states which key theoretical concepts are directly addressed through the design portion, and which best practices are recommended. Part VI addresses design approaches derived from the research portions and is the design portion of the thesis, highlighting the selected sites. Part VII, the last portion of the thesis, will conclude with summarizing the research and lessons learned.

## 1.5 SCOPE OF THE PROJECT

Watershed degradation affects a varied domain of disciplines. Sociology, engineering, architecture, planning, policy, landscape, biology, and food production are some of those disciplines. The goal of the research portion of the dissertation is to explore a multidisciplinary approach to Hawai'i's resolute watershed management model. However, the exploration is at the extent of the conceptual. Technical solutions to hydromodification are not covered in this dissertation. It is impossible to cover every discipline that watershed degradation relates to. However, the research justifies the strengths and values of green infrastructure solutions that amalgamates theories of landscape, identity, memory, ecology, and indigenous knowledge into a design solution. Among the literature, studies, and precedents, there are two important aspects of the research portion from which the design methodology is derived.

First, it is a key goal in the design process to express the importance of landscape and the *genius loci*, its role in the development of *places with meaning*, its perpetuity in the evolution of mankind and culture, and its role in the design process as a catalyst to derive tangible attributes. Second, the hydromodification approaches that were implemented in the watershed and those mentioned in the precedent studies will be analyzed, wherein the evolution of manmade changes in the natural environment throughout the watershed's history will be measured and compared against the ahupua'a model and emergent models.

The design of a solution will be approached at different scales: the watershed and selected sites along the Mānoa Stream. The final products are landscape interventions that address both the latent characteristics of the watershed and the infrastructural needs of the watershed.

## **II RESEARCH PORTION**

## 2.1 LANDSCAPE AND THE GENIUS LOCI

*“Consult the genius of the place in all  
That tells the waters to rise or fall  
Or helps the ambitious hills the heavens to scale  
Or scoops in circling theatres the vale...”*<sup>20</sup>

### Genius Loci

The architect and phenomenologist Christian Norberg-Schulz defines *genius loci* as “representing the sense people have of a place, understood as the sum of all physical as well as symbolic values in nature and the human environment.”<sup>21</sup> He states that man-made places relate to nature in three ways: when human beings visualize an understanding of nature, when humans create symbols of their understanding, and when humans use this understanding to create society.<sup>22</sup> Norberg also explains that the natural conditions of a place—topography, sky and cosmological lights, buildings, and symbols and meanings in the cultural landscape—contrasted with temporality of the landscape create the *genius loci*. The *genius loci*, which is a place in nature, is to be interpreted when we alter our environment.<sup>23</sup>

The *genius loci* is the principal character or atmosphere of a place. Aspects of the *genius loci* are apparent in the definition of landscape identity. What gives a landscape an identity is the physical features of a site that give it a unique spatial character and the relationship of humans to that characteristic, and the symbols they create for their environment. In *Perspectives on Landscape Identity: A Conceptual Challenge*, Stobellar and Pedroli identify landscape as “unique features of a landscape, rooted in time, visible and recognizable, distinguish the landscape from other landscapes and play a role in the collective living memory of its inhabitants.”<sup>24</sup> In *Elements of Visual design in the Landscape*, landscape architect Simon Bell states that “the *genius loci* is that quality or characteristic which makes one location or landscape different from any other, and that is unique and

---

<sup>20</sup> Alexander Pope and Herbert Davis, *Poetical Works*. (London; New York: Oxford U.P., 1966), 314-321.

<sup>21</sup> Gunila Jive'n and Peter J. Larkham, "Sense of Place, Authenticity and Character: A Commentary," *Journal of Urban Design* 8, no. 1 (2003): 70.

<sup>22</sup> Panita Karamanea, "Landscape, Memory and Contemporary Design," ed. Kay Lawrence, *Craft+design Enquiry*, no. 7 (2015): 115, accessed December 14, 2016.

<sup>23</sup> Christian Norberg-Schulz, *Genius Loci: Towards a Phenomenology of Architecture* (New York: Rizzoli, 1980), 25-32.

<sup>24</sup> Derk Jan Stobbelaar and Bas Pedroli, "Perspectives on Landscape Identity: A Conceptual Challenge," *Landscape Research* 36, no. 3 (2011): 321-339.

*individual to it...It is, however, a most important attribute in a place and may be fragile and vulnerable when changes occur in or around the particular location.*<sup>25</sup>

## **Landscape**

Landscape has many meanings and a variation of uses as a word. The landscape defined for this research is related to memory and identity. Simon Schama in *Landscape and Memory* says, “Before it can ever be a repose for the senses, landscape is the work of the mind. Its scenery is built up as much from the strata of memory as from layers of rock.” In *Discovering the Vernacular Landscape*, J. B. Jackson, an influential landscape writer, states that landscape “is a portion of the earth’s surface that can be comprehended at a glance.”<sup>26</sup> It is a clue for culture<sup>27</sup>; how we interpret human daily life and action, for we see and make landscapes through a collective system of beliefs dreams and ideologies. It is our legacy, and in *The Making of the English Landscape*, W.G. Hoskins, a landscape historian, expresses that landscape is “the greatest historical (and living) record we possess.”<sup>28</sup>

## **Memory**

According to Karamanea, “the concept of memory is always located in a historic context and is strongly linked to a place.”<sup>29</sup> In an effort to preserve memories, humans create paintings, literature, music throughout history. Memory can take on a physical form through the built environment. Historic events become immortalized as part of the built environment such as Independence Hall and the Liberty Bell.

## **Summary**

Landscape is a work of the mind, and without people, the landscape does not exist. The interaction between human society and the *genius loci*, the characteristics of a landscape, contribute to the collective memory—intangible things of a society that pass down the generations and inform culture. Symbols, meanings, and rituals are human expression of the

---

<sup>25</sup> Bell, S., 1993, *Elements of Visual Design in the Landscape*, London and New York: Spon Press. 119

<sup>26</sup> John Brinckerhoff Jackson, *Discovering the Vernacular Landscape* (New Haven: Yale University Press, 1984), 8.

<sup>27</sup> D. W. Meinig and John Brinckerhoff Jackson, "Fundamentals: Axioms for Reading the Landscape: Some Guides to the American Scene / Peirce F. Lewis," in *The Interpretation of Ordinary Landscapes: Geographical Essays* (New York: Oxford University Press, 1979), 11-32.

<sup>28</sup> W. G. Hoskins and Christopher Taylor, *The Making of the English Landscape* (London: Hodder & Stoughton, 1988), 14.

<sup>29</sup> Karamanea, 117.

landscape. The ritualistic things, like the acts of daily life, are human expression of their perception of their surroundings. Humans memorialize these actions in forms of symbolic attachment to tangible and intangible elements in the landscape.

Figure 5: Duke Statue at the Waikīkī waterfront, a tangible element in the landscape.  
Source: Susan<sup>30</sup>

For example, almost every Waikīkī postcard has a view of Laē‘ahi or Laē‘ahi, the perpetual backdrop to Waikīkī. For the foreigners and tourists who have these postcards, it is a symbol of a tropical ocean paradise landscape. However, with the same view, ancient Hawaiians saw it as the home of Pele, and the seat of power where the ruling elites of O‘ahu made their home. Another symbol is the famous Duke statue that surfers and beach-goers visit and hang leis on the statue. In the act, they perform a ritual – whatever everyone’s motive is – the fact remains that the statue has become a symbol for safety at sea or enjoyment of the Waikīkī shore.

### **Context and Significance**

---

<sup>30</sup> Susan, "Duke Kahanamoku Memorial Statue," digital image, Flickr, August 10, 2012, accessed December 10, 2016, <https://www.flickr.com/photos/riosmom03/7840984234>.

Landscape identity has two aspects: one refers to the physical features of a site that give it a pronounced spatial characteristic, and the other relates to the relationship of humankind to the particular space, and what it means to them. The landscape of ancient Waikīkī, like the rest of Hawai‘i was a coexistence between the natural environment and the human society. They had a spiritual and somatic relationship with their landscape. In contrast, the landscape of the current Ala Wai Watershed is a separation between the natural and human society wherein the urban environment has a parasitic relationship to the natural environment.

Figure 6: The Planter  
Source: Herb Kawainui Kane<sup>31</sup>

Ancient Waikīkī is described in its literal translation as the “place of spouting waters.” The ahupua‘a was a green watershed that was fed by streams, underground springs, the oceans, and the rains. Waikīkī was once a sacred site for healing, sacrifice, and it was favored as the dwelling and surfing spot by the ali‘i. The ahupua‘a of Waikīkī was once filled with agriculture and aquaculture, fed by the streams that flowed from three valleys – Makiki, Mānoa and Pālolo.

In *Waikīkī: A History of Forgetting and Remembering*, Feeser describes the ancient landscape: “*Waikīkī was thus suffused with the mana of the sacred rulers, who in their roles as providers*

---

<sup>31</sup> Herb Kawainui Kane, "The Planter," digital image, Island Breath, June 3, 2006, accessed December 10, 2016, <http://www.islandbreath.org/2006Year/16-farming/0616-02GMOandTaro.html>.



*oversaw the vast taro and fish-farming complex established in the area. Maka‘āinana tended Waikīkī’s lo‘i and loko and collected and caught food from the shore and ocean depths... Waikīkī’s waters also provided the kānaka maoli with sport and leisure and healing springs.”*<sup>32</sup>

Today, the Ala Wai Watershed is described as an urbanized watershed on the southern shores of O‘ahu. The watershed includes the three major streams, Makiki, Mānoa, and Pālolo which empty into the Ala Wai Canal, a 2-mile long channel separating the Waikīkī district from the valley and uplands of the watershed. The streams have been altered from their natural pattern and now function only to carry storm water from the urbanized areas into the canal, and out into the ocean.

The watershed is home to about 15% of the state’s population and the Waikīkī district hosts thousands of transients every day. Waikīkī is an urban resort that boasts an enhanced beach that extends from Ala Wai Harbor to Kapi‘olani Park. Several large hotels were built at the shoreline, blocking important views to the *mauka* valleys from the oceanfront.

---

<sup>32</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering* (Honolulu: University of Hawai‘i Press, 2006), 5.

## 2.2 WATER

### Water is Life

Creation stories from around the world begin with water. Water is our ancient mother.<sup>33</sup> From the darkness of the deep ocean, the earth emerged. The earth became a mother as well when creatures walked out from the oceans as primordial quadrupeds and stepped on earth to evolve into the bipedal man. According to the Kumulipo, “the water was made to be a nest that gave birth and bore all things in the womb of the deep.”<sup>34</sup>

Water is life and we have always had a somatic relationship with it.<sup>35</sup> Water sustains our minds and bodies. Our brains float on cerebrospinal fluid and our bodies must always be hydrated to maintain and regulate functions. Water is our fetal home from which we emerged and gained consciousness. All humans are mostly liquid, an ancestral trait inherited from our mothers and an ever-present symbol of that somatic relation. Eventually, we too will continue the water cycle and impart our genetic aqua-philía to the next generation. In the end, water is also death. Our unconscious bodies will return to the earth and the waters in the soil will bear us back into the deep oceans.

Memory and cultural identity is found in the water. When we return to water, we become part of the world’s ancient collective memory. Water has been described and given countless metaphors throughout time and evolution. It has been god, religion, rebirth, sustenance, inspiration, time, emotion, refuge, adventure, death, and a mirror into the unconscious.

The role of water in the environment relates to the dissertation in several ways and is described in the subsequent sections:

- Water is the sculptor for landscape.
- Water attracts people.
- Water was the most sacred resource in the ahupua‘a.

---

<sup>33</sup> Jorg-Dietram Ostrowski, *Phenomenology of Water & A Scenario for Downtown Waterfronts*, Master's thesis, Massachusetts Institute of Technology, 1975, 7, accessed December 14, 2016, <http://hdl.handle.net/1721.1/78380>.

<sup>34</sup> Martha Warren Beckwith, *The Kumulipo, a Hawaiian Creation Chant*, (Chicago: University of Chicago Press, 1951), First Verse.

<sup>35</sup> David W. Orr, *Earth in Mind: On Education, Environment, and the Human Prospect* (Washington, DC: Island Press, 2004), 54.

- Water should be a design driver in the attempt to reconnect the built and natural environment.

### **Water as Sculptor**

Naturally, water takes on many forms. It may appear as a drop, a trickle, as rain, ice, lakes, rivers, streams, and seas. Water, in all its forms, has shaped our landscapes and continues to do so.<sup>36</sup>

*“And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters.”<sup>37</sup>*

Stalactites and stalagmites form from single drops of water and ultimately join the land as mineral deposits. Rain slowly whittles away at mountains and hills, but carry rich soils for the dryer parts of the landscape. Streams, evanescent at any form and stage, wind through, following the path of least resistance on their way to the ocean. The flowing water twists and turns, shaping the land around them just as the landscape shapes and creates the path of the water. The reciprocal nature of water and the landscape is requisite to having a perpetually balanced natural evolution in the environment. Water and land should be each other's fringe to ensure optimal evolutionary processes. To ensure that water pervades and the *terra firma* ameliorates in rhythmic interchange, they should not be impeded by urban tectonics.

Figure 7: The changing coastline of Chatham Massachusetts.  
Source: Duncan Fitzgerald and Joseph Melanson<sup>38</sup>

---

<sup>36</sup> Ibid.

<sup>37</sup> Gen. 1:2.

<sup>38</sup> Duncan Fitzgerald and Joseph Melanson, "Breaching the Beach," digital image, Oceanus Magazine, accessed December 10, 2016, <http://www.whoi.edu/oceanus/v2/article/images.do?id=2484>.

In cities, water is also a sculptor, albeit its presence is weak in the urban fabric today. The rise and fall of civilizations is related to water. Hunter-gatherer communities migrated to different locations throughout the year, following the season for water and food. Eventually, the wandering communities established permanent settlements, which were logically situated near bodies of water for agricultural irrigation and transportation.<sup>39</sup> Numerous ancient civilizations experienced lengthy declines or quickly collapsed because of the scarcity of freshwater. Water, above all, is the basic requirement for survival.<sup>40</sup>

There are examples from antiquity and present day that validate potential coexistence between a rigid urban set and an untamed natural process. For example, the City of Ur, an ancient city of Mesopotamia was established on the Euphrates River. The city sits atop a tel, an artificial mound to protect the city from floods, surrounded by a wall and the Euphrates River. "*Controlling this outlet to the sea, Ur was favorably located for the development of commerce and for attaining political dominance.*"<sup>41</sup> The Euphrates was also a defensive layer for the city, and served as a transportation network because it could enter the city's walls through a waterway that ran through the heart of Ur, like an artery, passing through the palace and its adjoining harbors.

Egypt was another civilization that synchronized with water. The Nile River is credited to the development of the Egyptian civilization, as it is the major water source in the desert surrounding Egypt. The flooding of the Nile is an annual, natural cycle that was consistent enough that the ancient Egyptians used its arrival as the key to their calendars. The coming of the flood had been celebrated since ancient times. But in 1970, the High Dam was built and the annual flooding stopped. Lastly, Venice as a city had to synchronize and deal with rising water levels for many centuries. The city is enduring; its braved flood tides, the *acqua alta*, and is still sinking. The Venetians chose to settle between the mouths of the Piave River and Po River. They had to learn to coexist with the natural processes of the rivers.

---

<sup>39</sup> Thomas Elmqvist, ed., *Urbanization, Biodiversity and Ecosystem Services : Challenges and Opportunities : A Global Assessment* (Dordrecht: Springer, 2013), 14-16, accessed December 16, 2016, <http://www.doabooks.org/doab?func=fulltext&rid=15534>.

<sup>40</sup> Robin Clarke, *Water: The International Crisis* (Cambridge, MA: MIT Press, 1993), 14-16.

<sup>41</sup> International World History Project, "Sumeria, The City Of Ur," Sumeria, The City Of Ur, accessed December 14, 2016, <http://history-world.org/ur.htm>.

Figure 8: The Nile before and after flooding.  
Source: Jacques Descloitres<sup>42</sup>

### **Water in Design**

Water is a dominant feature in the environment and it derives its qualities from its context. If the environment changes, the characteristics of the water follow suit. Through observation, water appears more in the natural setting than in urban environments. Water in a natural landscape has various qualities that are sensorial and associative. The investigation into water and land's form and function is a tool to show the role of water in the landscape aesthetic for the design application portion of the design-research methodology.

---

<sup>42</sup> Jacques Descloitres, Flooding of the Nile, digital image, Earth Observatory, August 11, 2003, accessed December 10, 2016, <https://earthobservatory.nasa.gov/IOTD/view.php?id=3708>.

According to Norman Booth, author of *Basic Elements of Landscape Architectural Design*, water has four general characteristics: motion, plasticity, sound, and reflectivity.<sup>43</sup> Further organization of the general topics makes it so that water can also be visually classified by its motion and its character. These visual classifications are: standing, flowing, falling, and spouting.<sup>44</sup> The visual classifications can also be analyzed within the landscape within parameters such as: physical and spatial attributes; edges and boundaries; and direction and orientation.

A body of water can be generally classified into two categories pertaining to motion: standing body, and moving body. Standing water is quiet, static, includes pools, ponds, lakes, puddles, and gently moving rivers. Moving water includes waterfalls, rapids, and blowholes. Plasticity states that water has no permanent shape, and its form is attributed to gravity. “For example, flowing water is attempting to reach a point of stability with gravity, but stagnant water expresses an equilibrium with gravity.”<sup>45</sup> Plasticity refers to the shape water takes when it is in a container. In urban settings, where there are fountains and pools, water takes the shape of a defined, usually rigid, container. In the natural setting, containers for water vary. Sound in water is produced by its volume and the amount of movement involved.<sup>46</sup> The sound of water is important to human to site interaction in design. Water can create sounds like trickling, bubbling, splashing, roaring, and other adjectives. Lastly, by responding to factors such as slope, temperature, wind, light, and container, water can reflect an image of its immediate environment and the character of its container and surroundings.<sup>47</sup>

Norman Booth furthers that water can also be visually classified by its type of motion and character: standing, flowing, falling, spouting. Standing water includes pools and ponds. Pools can be used for reflection and contemplation; reflectivity becomes a key characteristic. Despite being soft and naturalistic, ponds are static and they can be used to link and unify the landscape, as well as create a feeling of repose and tranquility.<sup>48</sup> Flowing water is water movement in response to a change in gravity between the ends of a defined channel (natural or man-made). This includes streams and rivers, and excludes falling water. Flowing water can

---

<sup>43</sup> Norman K. Booth, *Basic Elements of Landscape Architectural Design* (New York: Elsevier, 1983), 254.

<sup>44</sup> Ibid., 261.

<sup>45</sup> Ibid., 255.

<sup>46</sup> Ibid., 256.

<sup>47</sup> Ibid.

<sup>48</sup> Ibid., 267.

be neutral and serene or have varying visual effects to excite.<sup>49</sup> Falling water occurs because of a sudden drop in elevation. This classification can express power through visuals, and sounds. There are three types of falling water: free-fall, obstructed flow, and sloped fall.<sup>50</sup> Free-fall is water falling from one elevation to another. Obstructed flow occurs when intermediate planes interrupt the falling water. Sloped fall is when water falls down a steep slope. Lastly, spouting waters is when liquid is discharged in a continuous stream from a usually narrow orifice. Spouting water include geysers, artesian wells, natural springs, and fountain jets.

The visual classifications can be analyzed with a set of parameters: physical and spatial attributes; edges and boundaries; and direction and orientation. Physical and spatial attributes are a description of the element; size, shape, quantity, and grouping or isolation are among the descriptors. For example, a body of water in its natural setting does not have a tectonic container. It's physical and spatial attributes might make it a wide continuous stream corridor that empties in the sea<sup>51</sup>, a linearly-oriented succession of disconnected little bodies of water that also point to the sea<sup>52</sup>, or a network of multiple-branching systems that feed into a trunk stream.<sup>53</sup> Edges and boundaries are a description of the portion of the body of water that meets with a body of land. Edges and boundaries can have vertical or horizontal in structure, size and width, ecological functions, abruptness, natural or urban, and hard or soft among other descriptors.<sup>54</sup> Direction and orientation inform the movement of the landscape's inhabitants through varying rhythms and physical characteristics. Direction deals with the changes in a user's movement or rhythm based on an element that either leads, shifts, or stops. For example, what might have been a quick walk across a footbridge over a canal suddenly turns into a shift in direction to a secondary path because the footbridge was closed for repairs. Orientation deals with sensorial cues for way-finding. For example, the sound of running water will lead you to the edge of a stream, the current will tell you which way it is to the sea.

## **Water and Man**

---

<sup>49</sup> Ibid., 268.

<sup>50</sup> Ibid., 270.

<sup>51</sup> Wenche E. Dramstad, James D. Olson, and Richard T. T. Forman, *Landscape Ecology Principles in Landscape Architecture and Land-use Planning* (Cambridge, Mass.: Harvard University Graduate School of Design, 1996), 40.

<sup>52</sup> Ibid., 38.

<sup>53</sup> Ibid., 42.

<sup>54</sup> Ibid., 28-32.

People have an intrinsic attraction to water. The presence of water is magnetic to humans and to animals as well. Many cultures began and center around bodies of water. The ancient Greeks tried to make sense of it when they allied their bodies of water with water nymphs, whom they believed had healing properties. The springs were personified by water nymphs who were often idealized as desirable, sensuous, wild, and free.<sup>55</sup> Greek tales tell us of men become crazed by the desire for an unattainable ideal. Water reflects the unattainable ideal which only exists in the unconsciousness.<sup>56</sup> It also symbolizes purity, rebirth, and is often the nexus of biological and cosmological cycles in cultures. It is used in religious practices such as blessings, baptisms, weddings, and funerals.<sup>57</sup> Our oldest civilizations were erected in proximity to rivers and streams and calm seashores. Ancient civilizations flourished through water, but their urban centers were also susceptible to the effects of chronological flooding. We do so much in, and to water that its significance to the individual's daily rituals is incredible.

Water is important for recreation, and people prefer to be in a waterfront setting. This is because the water being symbolic of flux presents us fresh sights, sounds, smells, sensations and create an environment<sup>58</sup> that gives a sense of freedom<sup>59,60</sup> which cannot be experienced in a deep urban setting. When man needs to feed his soul and fantasies, he journeys to the water's edge and performs rituals.<sup>61</sup> The water is an essential component for water-dependent activities, and water-enhanced activities, which are independent of the resource (e.g. jogging). In 2015, approximately 50% of all Americans (142 million) participated in at least one outdoor activity. The top outdoor activity for the nation was paddle sports.<sup>62</sup> In the same year in Hawai'i, 33% of inhabitants (465,000) participated in outdoor activities. The top outdoor activity for Hawai'i was visiting the beach.<sup>63</sup>

Both the nation and Hawai'i recognize water-dependent activities as the top outdoor activity. While investments in water access and activities for the water's edge are necessary for

---

<sup>55</sup> Sylvie Shaw and Andrew Francis, *Deep Blue: Critical Reflections on Nature, Religion and Water* (London: Equinox Pub., 2008), 34.

<sup>56</sup> Ibid., 180-183.

<sup>57</sup> Ibid., 11.

<sup>58</sup> Ibid., 145.

<sup>59</sup> Ibid.

<sup>60</sup> Ibid., 151.

<sup>61</sup> Ostrowski, 15.

<sup>62</sup> Outdoor Foundation, *Outdoor Recreation Participation Topline Report 2016*, report, 2016, 2015 Positive Outdoor Trends, accessed December 14, 2016

<http://www.outdoorfoundation.org/pdf/ResearchParticipation2016Topline.pdf>.

<sup>63</sup> DLNR, *Hawai'i Statewide Comprehensive Outdoor Recreation Plan 2015 Update*, report, ed. Department of Land and Natural Resources (National Park Service, 2015), 61.



economic and social growth, priority should also be given to protecting the water resource and the watershed from over-use and potential contamination. *“The wise use of water is quite possibly the truest indicator of human intelligence, measurable by what we are smart enough to keep out of it.”*<sup>64</sup>

### **Context and Significance**

Water is the driver of landscape. Memory and cultural identity is preserved in water. Water attracts people, and we have always had a somatic relationship to water. It’s presence in the urban context will promote awareness, stewardship, and recreation. In the Ala Wai Watershed, it will serve as the catalyst and connecting natural element that will bind the entire ahupua‘a from its physical, social, and psychological disconnected state. The design solution will center around water. Combinations of certain aspects of water’s characteristics that were described above will serve as a generative design tool in the eventual appearance and integration of water within the urban environment.

---

<sup>64</sup> Orr, 55.

## 2.3 THE EDGE AND THE WATERFRONT

### The Water's Edge

*"We return to the magnetism of water which forces us unknowingly to patronize the edge between earth and water, land and sea. A sandy beach, a riverside promenade the edge of a pool, a water pump and several living bridges."*<sup>65</sup>

The Public Trust Doctrine is an ancient Roman principle that the sovereign holds in trust for public use some resources such as shoreline regardless of private property ownership. This doctrine provides for the right of the public to access the water's edge.

An edge is the boundary or interface between elements, in this case, between the land and the water. The edge is a zone of exchange, not separation. And as Hawai'i's south shore becomes denser with non-stop construction and trends in population increase, inhabitants will require greater access to the water's edge.

The condition of the edge either allows or disallows accessibility.<sup>66</sup> The edge's structure, dimension, permeability, abruptness, curvi-linearity, straightness, shape, and orientation are a few parameters to consider when treating the edge. The types of activities and human interactions will happen at the waterfront must also directly influence the treatment of the edge.<sup>67</sup>

The dimension of the edge informs what kinds of functions and activities can happen along the water. The permeability of the edge to function as a filter between the two elements<sup>68</sup> would be good for large edges that have enough room for biological functions and space for human activity as well. Increased abruptness of an edge tends to increase direction of movement along the edge, as does a straight edge and a more gradual sloped edge allowed movement across the two elements, as does a curvilinear element.<sup>69</sup> The shape of the edge in conjunction with its dimension determines how much functions and activities can happen. The presence of reciprocal convoluted coves and lobes on the edge<sup>70</sup> as opposed to a straight edge promotes not only human movement across the two elements, but also encourages growth and interaction between the biological functions of a planted with its surroundings.

---

<sup>65</sup> Ostrowski, 53.

<sup>66</sup> Dramstad, et al., *Landscape Ecology Principles*, 27.

<sup>67</sup> Ibid., 28-32.

<sup>68</sup> Ibid.

<sup>69</sup> Ibid., 29-30.

<sup>70</sup> Ibid., 31.

There are two general types of edges. Edges that densely vegetated patches and extend over long distances are called “soft edges.”<sup>71</sup> An example of this would be a gently sloping horizontal plane like a gradual transition between a marsh and the beach. On the other hand, edges that are abrupt and have no transition between the two elements that it bounds are called “hard edges.”<sup>72</sup> An example of a hard edge is a bulkhead, or a seawall.

## **Waterfront**

The waterfront is the space where land and water merge or confront each other.<sup>73</sup> It is an area sandwiched between the natural and the urban, it is on the water’s edge.<sup>74</sup> The waterfront has been described in the most poetic ways; it is the border between two worlds, two forces, like yin and yang, black and white, dry and wet, hard and soft. It unites and divides. It is a tangible threshold for intangible truths like freedom, infinity, flux, in-animacy, no-where, and abstract.<sup>75</sup>

Water and land are in complimentary opposition. The different aspects and qualities of the other silently and forcefully are present in each and becomes the dominant driver in the physical form of their shared edge. The physical form of the merging entities leads to the emergence of “places” on the water’s edge, thus the waterfront. The waterfront is the synthesis of urban processes with the natural processes. It gains its own identity and appends to the existing landscape as humans make use of the waterfront and create memories.

*“On downtown waterfronts, we found such festivals taking place. We went on expeditions to the harbors to witness the thrills of massive ships and grain elevators. We fished from the wharfs. We played in the waterfront playgrounds where we could use the earth and water.”*<sup>76</sup>

The transformation of the waterfront into one of the most prestigious locations in the city made its location sought after for services, offices, housing, and recreation and by the

---

<sup>71</sup> Susan Bannerman and British Columbia. Ministry of Forests. Research Branch., *Biodiversity and Interior Habitats : The Need to Minimize Edge Effects. Part 6 of 7* Part 6 of 7 (Victoria, B.C.: Ministry of Forests, Research Program, 1998), 3.

<sup>72</sup> Ibid., 3.

<sup>73</sup> Ann Breen, *Waterfronts: Cities Reclaim Their Edge* (New York: McGraw-Hill, 1994), 2.

<sup>74</sup> Rinio Bruttomesso, *The Oriental Dimension of the Waterfront : Waterfront Reorganisation in Singapore, Jakarta, Kuala Lumpur, Bangkok, Saigon and Sydney* (Venezia: Marsilio, 1997).

<sup>75</sup> Aleksander Sasa Ostan, "Tierra Agua: Paisaje Dual," *Quaderns D'Arquitectura I Urbanisme* Tierra-Agua, no. 212 (1996): 44-45, accessed December 16, 2016.

<sup>76</sup> Ostrowski, 53.

public.<sup>77</sup> With the major changes in land use, new myths and stories, displaced actors and new actor groups, and the general change in the physical attributes of the site. Different urban processes are happening simultaneously at the new waterfront creating new memories and forming a new identity for itself and for the urban environment and for the natural environment. The waterfront is a powerful place. People are drawn to it and find its edge an attracting and exciting place to be. The waterfront is the city and water's interaction. The interaction provides the largest public space<sup>78</sup> that is neither or, but nestled between the urban setting, and the natural environment.

Figure 9: A celebration on the waterfront.  
Source: Delaware River Waterfront<sup>79</sup>

### **Context and Significance**

The importance of the water's edge and the waterfront in the Ala Wai Watershed cannot be overlooked. The waterfront provides the largest public space nestled between the

---

<sup>77</sup> Hans Harms, *Changes on the Waterfront - Transforming Harbor Areas: Comparison and Evaluation of Waterfront Developments in Two Contexts: San Francisco Bay Area and Hamburg, Germany*, working paper (Berkeley: University of California, Berkeley, 2007), 17.

<sup>78</sup> Eileen McHugh, *Landscape and Memory: Transformation of an Urban River's Edge*, Master's thesis, Massachusetts Institute of Technology. Dept. of Architecture, 1998 (Massachusetts Institute of Technology, 1998), 13, accessed December 16, 2016, <http://hdl.handle.net/1721.1/68787>.

<sup>79</sup> "Sugarhouse New Year's Eve Fireworks on the Waterfront," digital image, Delaware River Waterfront, December 1, 2015, accessed December 10, 2016, <http://www.delawareriverwaterfront.com/planning/news/new-year-s-eve-at-the-waterfront7>.

urban setting and the natural environment. It is an area for habitat, for recreation, for contemplation, and for excitement. Part of what makes the Waikīkī District so appealing is its waterfront, and part of what makes the entire Waikīkī ahupua‘a so beautiful is its physical and mythical associations with water. The stream and streamlets that run down from mountain to sea, the springs, the stretch of sandy beach, the Ala Wai Canal promenade, and the harbor are all different waterfronts and different treatments of the edge within the watershed. Preserving and enhancing these features within the landscape will strengthen their claim as part of the Ala Wai Watershed landscape in its amalgamated physical characteristics, the memories of the different types of people who are attracted to the different edges, and the current and future meanings of these places.

## 2.4 WATERSHEDS

### The Watershed

We all live in a watershed and the shed's condition is important to everyone who uses water. A watershed, also called a drainage basin, is an extent of land where all the water from precipitation converges and drains into a common outlet and joins another body of water such as a river, a lake, or an ocean. A watershed receives, collects, and transports precipitation on a landscape.<sup>80</sup> Watersheds have also been historically important for determining territorial and political boundaries.<sup>81</sup> All land, natural or urbanized, is part of the watershed. "The size of watersheds can be as small as a footprint or as big as the lands that drain water into rivers that empty into Chesapeake Bay and then into the Atlantic Ocean."<sup>82</sup>

Figure 10: Cross Section Diagram of a Watershed.  
Source: Martha Barss<sup>83</sup>

---

<sup>80</sup> USGS, "What Is a Watershed?," Watersheds and Drainage Basins, USGS Water Science School, A watershed is a precipitation collector, accessed December 16, 2016, <http://water.usgs.gov/edu/watershed.html>.

<sup>81</sup> Daniel Löwenborg, "Watersheds as a Method for Reconstructing Regions and Territories in GIS," in *Digital Discovery. Exploring New Frontiers In Human Heritage* (2007), 129.

<sup>82</sup> USGS, "What Is a Watershed?"

<sup>83</sup> Martha Barss, "Watershed Cross Section Diagram," digital image, RPCS.org, September 8, 2012, accessed December 10, 2016, <http://sp.rpcs.org/faculty/BarssM/geoandeco/WebsitePictures/Forms/DispForm.aspx?ID=30>.

Much of the water in the watershed originates as precipitation. They move through the watershed on a network of branching waterways that is responsible for the structure and organization of the different ecosystems within a watershed. The network begins at the highest elevation of the watershed. Water falls on the ridges of the steep and mountainous uplands. From the headwaters, ephemeral tiny rivulets, the water flows downhill and join rills and gullies and eventually into creeks, and then into the streams. Eventually, the tributary streams merge into trunk streams and exit into the ocean.<sup>84</sup>

Some of the precipitation flows along the surface and join surface waters like lakes, streams, ponds, rivers, wetlands, and manmade "flood" controls as runoff.<sup>85</sup> Surface water returns to the atmosphere through evaporation depending on temperature, wind, sun energy, humidity, and other factors. Transpiration, which is evaporation through plants, depends on the characteristics and density of vegetation and the same factors as evaporation.<sup>86</sup> The remainder of the precipitation soaks into the soil. Some water that infiltrates remains in the shallow soil layer and eventually seep into the banks of a surface water. Some water infiltrates deeper as recharge and enters the groundwater system where it will be stored into underground aquifers.<sup>87</sup>

The greatest factor controlling flow is the amount of precipitation that falls in the drainage basin and the rate during which it falls. Not all precipitation that falls in a watershed becomes runoff or recharge. About 60% of the precipitation that lands in the basin is absorbed by plants.<sup>88</sup> Permeability and soil characteristics also affect the flow of water through the watershed. Water absorbs slowly in steeply-sloped land and increases the speed of runoff. Gently-sloped land allows water to absorb easier and decreases the speed runoff. Well drained sandy soils absorb water easily, reducing runoff, while clays and rocky soils absorb less water and boost surface runoff. Furthermore, soil that is already saturated from previous rainfall can't absorb much, therefore, more rainfall will become surface runoff.<sup>89</sup> Precipitation that

---

<sup>84</sup> Arthur Bloom, *Water Encyclopedia: Science and Issues*, s.v. "Stream Erosion and Landscape Development," Rivers and Landscape Shaping, accessed December 16, 2016, <http://www.waterencyclopedia.com/St-Ts/Stream-Erosion-and-Landscape-Development.html>.

<sup>85</sup> "Movement of Water," Movement of Water, accessed December 16, 2016, <https://msnucleus.org/watersheds/General/watermove.htm>.

<sup>86</sup> USGS, "Transpiration - The Water Cycle," The Water Cycle (Water Science School), accessed December 16, 2016, <http://water.usgs.gov/edu/watercycletranspiration.html>.

<sup>87</sup> USGS, "What Is a Watershed?"

<sup>88</sup> City of Wixom, Michigan. "Watershed." Wixom, MI : Watershed. Accessed December 16, 2016. <http://www.wixomgov.org/government/public-works/watershed>.

<sup>89</sup> USGS, "What Is a Watershed?"

lands on impervious surfaces, such as parking lots, and roads go into storm drains that drain directly into streams. Vegetation and permeable surfaces hinder runoff and allows the water to infiltrate.<sup>90</sup>

The upper area of a watershed encompasses the ridges of the watershed down to a valley. The upper areas of a watershed that are forested contribute to good water quality, increased infiltration, and reduced erosion.<sup>91</sup> According to the USDA, “*approximately 80 percent of U.S. fresh-water resources are estimated to originate in forests.*”<sup>92</sup> The rain forest acts like a sponge by filtering water through its layers of vegetation.<sup>93</sup>

Figure 11: The layers of a rainforest.  
Source: Rainforest Rescue<sup>94</sup>

Most rainforests are structured in four interdependent layers: emergent, canopy, understory, and forest floor. Each layer has characteristics that mitigate erosion, delay the rain

---

<sup>90</sup> USGS, "Infiltration - The Water Cycle," Infiltration - The Water Cycle, from USGS Water-Science School, December 15, 2016, Factors affecting infiltration, accessed January 19, 2017, <https://water.usgs.gov/edu/watercycleinfiltration.html>.

<sup>91</sup> Marin County Department of Public Works, "Anatomy of a Watershed," Marin County Watershed Program, Uplands, accessed December 16, 2016, <http://www.marinwatersheds.org/anatomy.html>.

<sup>92</sup> USDA Forest Service Southern Research Station, "Fish & Wildlife Research Areas," USDA, Stream Restoration, accessed December 16, 2016, <https://www.srs.fs.usda.gov/research/fish-and-wildlife/>.

<sup>93</sup> Elliot Richmond, *Water Encyclopedia: Science and Issues*, s.v. "Forest Hydrology - Building, Effects, Important, Types, Plants, Human," Water and Forested Ecosystems, accessed December 16, 2016, <http://www.waterencyclopedia.com/En-Ge/Forest-Hydrology.html>.

<sup>94</sup> Save the Rainforest, "The Layers of the Rainforest," digital image, Rainforest Rescue, accessed December 10, 2016, <http://rainforestrecue.weebly.com/layers-of-the-rainforest.html>.



from reaching the surface, and filter the water.<sup>95,96</sup> The emergent layer consists of a few trees that tower over the rest; they emerge from the dense forest canopy. The trees can grow as tall as 200 feet and retain water in their leaves and branches.<sup>97</sup> The canopy layer is beneath the emergent layer and forms the primary layer of the forest. It is a deep layer of vegetation about 20 feet thick. The canopy blocks wind, a lot of sunlight, and breaks up the falling rain to create a humid and dark environment below. The rain that falls on the canopy bounce on the trees' water-repellant leaves and slowly stream down the trees' trunk.<sup>98,99</sup> The bottom of the canopy is called the understory. The understory is a layer of baby trees, shrubs, and soft stemmed plants such as ferns. The understory creates a darker and far more humid environment near the ground to hinder evaporation.<sup>100,101</sup> The forest floor layer is very dark, and the air is still. The forest floor consists of fungi, moss, grasses, and decaying leaves and matter. Decomposer organisms break down the decaying matter into nutrients. This layer serves to keep the soil in place and filters the water before it infiltrates or flows down taking nutrients with it.<sup>102</sup> An expansive, healthy forested upland can mitigate the pressure on the watershed's coastal wetlands.

The wetland is an ecotone, an "edge" habitat, between dry land and deep water. It is an area that is neither terrestrial nor aquatic.<sup>103</sup> There are many types of wetlands—bog, estuary, marsh, swamp, fen, mangrove, mire, moor, and slough—and they are all either periodically or permanently saturated in water.<sup>104</sup> The type of wetland is what it needs to be because of its relationship to other ecosystems within the total watershed. Wetlands form in areas where the land is flat or slightly depressed, where the soil contains hydrogen and is un-drained, where infiltration is slow, and where groundwater spouts.<sup>105</sup> Natural wetlands are

---

<sup>95</sup> Andrew Turgeon, *National Geographic Society*, ed. Caryl-Sue Micalizio, s.v. "Rain Forest," May 11, 2015, Rain Forest Structure, accessed December 16, 2016, <http://www.nationalgeographic.org/encyclopedia/rain-forest/>.

<sup>96</sup> Smithsonian Institute, *Smithsonian Tropical Research Institute*. "Rainforests," How They Work, accessed December 16, 2016, <http://www.stri.si.edu/sites/rainforest/index.html>.

<sup>97</sup> Turgeon, "Rain Forest," Emergent Layer.

<sup>98</sup> Ibid., Canopy Layer.

<sup>99</sup> Smithsonian Institute, "Rainforest," Canopy.

<sup>100</sup> Ibid., Understory.

<sup>101</sup> Turgeon, "Rain Forest," Understory Layer.

<sup>102</sup> Smithsonian Institute, "Rainforest," Forest Floor.

<sup>103</sup> Donald A. Hammer, *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural* (Chelsea, MI: Lewis Publishers, 1989), 5.

<sup>104</sup> Thomas C. Winter and N. Earl Spangenberg, *Water Encyclopedia: Science and Issues*, s.v. "Wetlands - River, Depth, Freshwater, Important, Types, System, Plants, Source, Marine, Oxygen, Human," Wetland Classification, accessed December 16, 2016, <http://www.waterencyclopedia.com/Tw-Z/Wetlands.html>.

<sup>105</sup> Hammer, 6.

ephemeral because they are *“highly dependent upon tectonic and hydrologic occurrences like earthquakes, flooding, and storms.”*<sup>106</sup> The most significant perturbation to the system is its periodic inundation and drying.<sup>107</sup> Without these occurrences, a wetland will gradually fill in and become dry land.

Figure 12: Kawainui Marsh  
Source: Hanako Kira<sup>108</sup>

Wetlands are important in the watershed's anatomy. These unstable transition zones receive, hold, recycle runoff from the uplands. Wetlands also protect water edges from wind and water erosion, attenuate flooding, and mitigate storm surges by absorbing tidal energy. The wetlands work hand in hand with the forested uplands to improve the water's quality before it enters the ocean. The wetlands are effective in filtering point source and non-point source pollutants like organic matter, metals, and excess nutrients that the runoff conveys.

---

<sup>106</sup> Ibid., 6.

<sup>107</sup> Ibid., 108.

<sup>108</sup> Hanako Kira, "Kawainui Marsh," digital image, Deviantart, December 21, 2011, accessed December 10, 2016, <http://hanakokira.deviantart.com/art/Kawainui-Marsh-3-275176530>.

Natural processes like filtration, sedimentation, decomposition, plant absorption and assimilation can remove pollutants from the water, or immobilize them in the wetlands.<sup>109</sup>

Wetlands are highly fertile from the nutrients that are transported from the upland regions. While they represent a small amount of land area, they support a large percentage of plant and animal communities.<sup>110</sup> These include emergent aquatic plants, brackish-water plants, shorebirds, fish, poikilotherms, invertebrates, amphibians, and some mammals. In the United States, more than 900 species of flora and fauna require wetland habitat and about one-third of the species that are federally listed as endangered or threatened depend on wetland habitats.<sup>111</sup> According to Hammer, *“of the 87 million hectares of wetlands in the United States when the colonists arrived, less than half remain today.”*<sup>112</sup>

Watersheds serve urban living spaces for people and act as habitat for biota. Since ancient times, they have provided ecological functions needed for biotic evolution and human civilization. High-quality watersheds have become scarce in the United States. Watershed management has become a necessity to maintain the ecological functions to provide healthy, habitable, urban living spaces for people and plants and animals.

### **Watershed Management**

Humans have been managing their watersheds for over 5000 years. From the start of agriculture, humans have been manipulating the landscape to benefit cultivation and control floods and mitigate the effects of droughts.<sup>113</sup> These early attempts to control water flow eventually evolved into sophisticated extended irrigation systems. Ancient civilizations in the Fertile Crescent developed irrigation systems in the watersheds of the Nile, the Euphrates, and the Tigris. From the Cradle, water engineering technologies spread to other cultures of the world.<sup>114</sup>

The *Atharva Veda* texts from 800 BC indicates the first definition for watershed management. It states, *“one should take proper managerial actions to use and conserve water from*

---

<sup>109</sup> Ibid., 12.

<sup>110</sup> Ibid., 108.

<sup>111</sup> Winter and Spangenberg, “Wetlands,” Conserving and Mitigating Wetlands.

<sup>112</sup> Hammer, 108.

<sup>113</sup> Food and Agriculture Organization of the United Nations (FAO), *The New Generation of Watershed Management Programmes and Projects: A Resource Book for Practitioners and Local Decision-makers Based on the Findings and Recommendations of an FAO Review* (Rome: Food and Agriculture Organization of the United Nations, 2006), 5.

<sup>114</sup> FAO, *The New Generation of Watershed Management Programmes and Projects*, 6.

*mountains, wells, rivers, and rainwater for use in drinking, agriculture, industries...*<sup>115</sup> The Mediterranean people became the forerunners of modern watershed management techniques. By 700 BC, Troy had aqueducts to bring water from distances, and in 400 BC, Rome built springs and wells for water supply.<sup>116</sup> In the Americas, as early as 200 BC, the Andean empires had developed a sophisticated watershed management model based on their upland, mountainous landscape.<sup>117</sup> They built extensive irrigation canals and insane amounts of terracing into their mountains to create a large artificial vertical, agricultural landscape, which probably inspired today's vertical farming.<sup>118</sup>

In the United States, watershed management began when national forest reserves were established through the Forest Reserve Act of 1891. The act was solely to “stop exploitation and destruction of the forests adjacent to Yellowstone National Park.”<sup>119</sup> However, the Forest Service Organic Administration Act of 1897 became an amendment that defined the purpose of the forest reserves. It stated that the reserves could be established to “*improve and protect the forest within the reservation, or for the purpose of securing favorable conditions of water flows...*”<sup>120</sup>

Between 1911 and 1945, the Forest Service focused on acquiring and reforesting watersheds throughout the East and Midwest. As a result, the Research Branch of the Forest Service was established in 1915. In 1917, the branch produced the one of the very first soils reports.<sup>121</sup>

After the Second World War, problems from the numerous dam and irrigation developments throughout the world raised awareness of the importance of a connected watershed. “Watershed planning started to seriously consider the impacts of processes as seasonal torrents, erosion, rapid basin saturation and downstream floods.” Planners had to consider the economic and social implications of watershed management.<sup>122</sup> In the late 1980s,

---

<sup>115</sup> Peter F. Ffolliott, Daniel G. Neary, *USDA Forest Service Proceedings RMRS-P-13. 2000*, proceedings of Land Stewardship in the 21st Century : The Contributions of Watershed Management : Conference Proceedings, Tucson, Arizona, March 13-16, 2000, Changing Perceptions of Watershed Management from a Retrospective Viewpoint, accessed December 16, 2016, [https://www.fs.fed.us/rm/pubs/rmrs\\_p013/rmrs\\_p013\\_167\\_176.pdf](https://www.fs.fed.us/rm/pubs/rmrs_p013/rmrs_p013_167_176.pdf).

<sup>116</sup> Ibid., 167.

<sup>117</sup> FAO, *The New Generation of Watershed Management Programmes and Projects*, 6.

<sup>118</sup> Ffolliott and Neary, 168.

<sup>119</sup> Stephen P. Glasser, “Short History of Watershed Management in the Forest Service: 1897 to 2100,” in *Advancing the Fundamental Sciences : Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004.*, ed. Michael J. Furniss (Portland, OR: U.S. Forest Service, Pacific Northwest Research Station, 2007.) 451.

<sup>120</sup> Ffolliott and Neary, 169.

<sup>121</sup> Glasser, 452.

<sup>122</sup> FAO, *The New Generation of Watershed Management Programmes and Projects*, 7.

watershed management re-focused on the role that development can play in protecting their resources.<sup>123</sup>

Watershed management continues to evolve. In its early stages, it focused on forestry and forestry-related hydrology. In the early part of the 20<sup>th</sup> century, watershed planning shifted focus on land resource management and economic benefits. In the latter part, watershed management focused on the role human populations have on the environment.<sup>124</sup> According to the Food and Agriculture Organization of the United Nations (FAO), watershed management is currently in a period of experimentation in which old and new practices are assimilating. The next generation watershed management approach calls for an integrated and participatory approach, a combination of the last two paradigm shifts. The management of the watershed should account for land and water attributes, the socio-economic factors which affect the development of urban areas, and land-use practice.

### **The Ahupua'a Model**

The ahupua'a model of watershed management is unique to the Hawaiian watersheds. Although no one knows exactly when the first colonizers arrived in Hawai'i, per archaeological evidence and oral tradition, the earliest inhabitants of the Hawaiian Islands arrived in 300 CE.<sup>125</sup> From their arrival, until 1778 when Captain James Cook found the islands, the ancient society flourished alongside their natural environment.

The ancient Hawaiians' watershed management reflected the somatic and filial relationship they had to their landscape and are based on the respect for nature. In fact, no one owned land because they believed everything belonged to the gods, and they were the dependent guests. They structured their society to be in-sync with their natural environment because they understood that dependency on their surroundings. The indigenous land management practice was sophisticated, evident of its capability to support and sustain a society of approximately one million ancient Hawaiians in its prime before foreign disease rapidly decimated the population.<sup>126</sup>

---

<sup>123</sup> Ibid.

<sup>124</sup> Ibid., 50.

<sup>125</sup> Kanahale, *Waikiki 100 BC to 1990 AD : An Untold Story*, 11.

<sup>126</sup> David E. Stannard, *Before the Horror: The Population of Hawai'i on the Eve of Western Contact* (Honolulu, HI: Social Science Research Institute, University of Hawai'i, 1989), 32-37.

The Hawaiians' political system was strict, but it placed extreme importance on the protection of the natural environment. No one was above the kapu, a code of conduct of laws and regulations that was absolute and universal in everyone's daily life. The kapu provided for a caste system that divided the population into societal roles-- ali'i (elites), who enforce the kapu and govern the people and resources; or maka'āinana (commoners), who nurture and cultivate the land. The kapu structured the ancient Hawaiian society into a hierarchy that paralleled the structure of their land management model.

The Hawaiians' comprehensive land management model started on the scale of mokupuni (island). The mokupuni, which was held in trust for the whole population by the ali'i nui (highest chief), was divided in large districts called moku. An ali'i'ai moku (lieutenant chief) oversaw a moku, which were each further subdivided into vertical arrangements called the ahupua'a.<sup>127</sup> The ahupua'a was governed by an ali'i'ai (lower chief), who then appointed a konohiki to serve as managers who closely monitored the use of the ahupua'a's resource systems.<sup>128,129</sup>

A typical ahupua'a's boundary began at the ridges of the mountain where the headwaters begin, becoming wider as it runs down the valley and its streams, and into the sea to the edge of the reef. The ahupua'a was at a scale in the island management model where the settlers could monitor and enhance the stream network and they could produce sufficient amounts of goods for themselves and for taxation without overwhelming the natural systems in their watershed.<sup>130,131</sup>

---

<sup>127</sup> Dieter Mueller-Dombois, "The Hawaiian Ahupua'a Land Use System: Its Biological Resource Zones and the Challenge for Silvicultural Restoration," ed. N.L. Evenhuis and J.M. Fitzsimons, in *Biology of Hawaiian Streams and Estuaries : Proceedings of the Symposium on the Biology of Hawaiian Streams and Estuaries : Hilo, Hawai'i, 26-27 April 2005*, 24, <http://hbs.bishopmuseum.org/pubs-online/strm/04-Mueller-Domboisr.pdf>.

<sup>128</sup> Ibid., 23.

<sup>129</sup> Luciano Minerbi, "Indigenous Management Models and Protection of the Ahupua'a," in *The Ethnic Studies Story: Politics and Social Movements in Hawai'i : Essays in Honor of Marion Kelly*, ed. Ibrahim G. Aoude and M. Kelly, vol. 39, Social Process in Hawai'i (Honolulu: Dept. of Sociology, University of Hawai'i at Mānoa, 1999), 212.

<sup>130</sup> Ibid.

<sup>131</sup> Mueller-Dombois, 24.

Figure 13: Breakdown of ahupua‘a  
Source: Kumukahi.org<sup>132</sup>

---

<sup>132</sup> Kumukahi.org, Ahupua'a, digital image, Kumukahi.org, accessed December 10, 2016, [http://www.kumukahi.org/units/ka\\_honua/onaepuni/ahupua'a](http://www.kumukahi.org/units/ka_honua/onaepuni/ahupua'a).

Figure 14: Ecological and human services within the watershed.  
Source: Luciano Minerbi<sup>133</sup>

---

<sup>133</sup> Luciano Minerbi, "Ahupua'a," digital image, Ho'okuleana, June 18, 2012, accessed December 10, 2016, <http://totakeresponsibility.blogspot.com/2012/06/ahupua'a-hawaiian-land-management-system.html>.



The boundaries of the ahupua‘a also depended on presence of ecological zones that each generated different resources because of a variety of climatic zones within the ahupua‘a.<sup>134</sup> There are three to five ecologic zones that subdivide the ahupua‘a. The three major ecological zones are the wao nahele, the upland rainforest zone; the wao kanaka, agricultural zone, and the kaha kai, the coastal zone.<sup>135,136</sup> In addition to the major zones, kai is the considered to be the ocean zone, the area succeeding the coastal zone, past the shore. Lastly, the ancient Hawaiians distinguished the freshwater stream network that ran from mauka (towards the mountain) to makai (towards the sea) as a separate ecological zone, the kahawai. As the kahawai reaches the kaha kai and turns brackish, it becomes known as a muliwai (wetland).<sup>137</sup>

Water shapes the landscape. The ahupua‘a, like all watersheds, is naturally organized by the network of streams and bodies of water within its drainage boundaries. The Hawaiians also shaped their landscape with sophisticated infrastructure, but demonstrated their respect for nature by adapting their technology to coexist with the natural environment.<sup>138</sup> They had a thorough knowledge base of their watershed, so they were conscious of the effects of their interventions. They constructed simple, and efficient infrastructure like the one for lo‘i (irrigated terrace) which was “a system with ‘auwai (ditches) to bring water from the streams into the lo‘i and mākāhā (locks) to regulate the water flow.”<sup>139</sup> The konohiki dictated the distribution of water for the lo‘i. The farmers would open the mākāhā, allow the amount of water the konohiki allotted to him, and close it again.<sup>140</sup> The konohiki also made sure that the ‘auwai and the lo‘i embankments were always repaired and strong to avoid seepage back into the stream. They had an understanding on changes of water quality in the lo‘i when it interacts with kalo (taro) and compost.<sup>141</sup>

Indigenous watershed management was a lifelong educational commitment, and it caused the ancient Hawaiians to be attuned and deeply observant of their environment. Through oral tradition and memorization, individuals had a thorough knowledge of mythical,

---

<sup>134</sup> Mueller-Dombois, 24., 24-25.

<sup>135</sup> Minerbi, 212-214.

<sup>136</sup> Mueller-Dombois, 24-27.

<sup>137</sup> Ibid., 27.

<sup>138</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 40.

<sup>139</sup> Ibid., 21.

<sup>140</sup> Betty Dunford et al., *The Hawaiians of Old* (Honolulu, Hawai‘i: Bess Press, 2002), 67.

<sup>141</sup> Board of Water Supply, *Water for Life The History and Future of Water on O‘ahu* (Honolulu, HI: Board of Water Supply), 6, accessed December 16, 2016, <http://www.boardofwatersupply.com/bws/media/files/publication-water-for-life.pdf>.

historical, biological, ecological, hydrological, social, geomorphological, and political functions of their specific watershed.<sup>142</sup> For example, early Hawaiians had more than two hundred words to describe rain and more than 600 variations to describe wind. “The kili noe is a fine, light rain, but it’s not to be mistaken for the kili ‘ohu, which was even finer and lighter...ho‘opala ‘ōhi‘a rain indicated when the native ‘ōhi‘a would ripen...apo pue kahi is a rain felt after a loved one passes.”<sup>143</sup> They also had countless plants and animals identified by names, they recognized different land forms and plant communities and distinguished types of ecosystems from others.<sup>144</sup>

Access to the watershed’s resources was based on privilege, which safeguarded a continued respect for the land. The ancient society sanctioned kapu that balanced input and output of resources and forbid extravagance and wasteful use of shared assets. They especially, strictly monitored and controlled the wai (water) which was sacred to them because they observed that it was a gift from the wao akua (the wilderness of gods), the upland forest enshrouded by clouds, and flowed down the watershed to bless them, who lived in the wao kanaka (the realm of the humans).<sup>145</sup> The konohiki who was responsible for the waters in the ahupua‘a made sure that the maka‘āinana worked together to keep the water pristine. They cleared and diverted the streams, they had to keep the communal streams as clean as possible, and the farmers were expected to maintain healthy and orderly lo‘i and loko (ponds).<sup>146</sup>

“The wise use of water is quite possibly the truest indicator of human intelligence, measurable by what we are smart enough to keep out of it.”<sup>147</sup> Breaking the kapu concerning the ahupua‘a was a serious offense and the punishment for certain actions resulted in death. “Those who failed to maintain resources or wasteful in its use were evicted and banished. If a farmer dared to water his fields without approval from the overseer, he was put to death.”<sup>148</sup>

### **Context and Significance**

---

<sup>142</sup> Mueller-Dombois, 24.

<sup>143</sup> Matthew Dekneef, "Hawaiians Have More than 200 Words for Rain," Hawai'i Magazine, March 04, 2016, accessed December 14, 2016, <http://www.Hawaiimagazine.com/content/Hawaiians-have-more-200-words-rain>.

<sup>144</sup> Mueller-Dombois, 24.

<sup>145</sup> *Last Stand: The Vanishing Hawaiian Forest* (Honolulu, HI: Nature Conservancy of Hawai'i, 2003), 7, 10.

<sup>146</sup> Board of Water Supply, *Water for Life*, 6.

<sup>147</sup> Orr, 55.

<sup>148</sup> Board of Water Supply, *Water for Life*, 6.

The ahupuaʻa declined when Westerners introduced foreign diseases to which the ancient Hawaiians had no immunity and brought cattle for ranching in the early 1800s.<sup>149</sup> In a mere 200 years, 64% of Hawaiʻi streams have become impaired by pollution, 98% of drinking water is sourced from the ground, which is rapidly depleting because of sea level rise, and our island population continues to increase, while fresh water supply is decreasing.<sup>150</sup>

Approximately 1.4 million people currently reside in Hawaiʻi today. The fact that the ancient model of watershed management sustained a million ancient Hawaiians without the need for external resources shows that our current watershed management approaches are subpar and unsustainable. It is an achievement that we must now constantly measure ourselves against and work towards.

Because of the interdependent relationship between their society and the natural environment, the ahupuaʻa model provided the ancient Hawaiians a millennium to enjoy a healthy natural environment. No one owned the land, and the fact that it belonged to the gods made it sacred and immortal. The aliʻi and makaʻāinana were held to a high standard of responsibility for their use of the landscape. Although the enforcement of the kapu might be considered harsh today, it functioned to preserve natural resources so that future generations could also prosper.

---

<sup>149</sup> State of Hawaiʻi Department of Agriculture, "History of Agriculture in Hawaiʻi," Department of Agriculture, January 31, 2013, accessed December 12, 2016, <http://hdoa.Hawaiʻi.gov/blog/ag-resources/history-of-agriculture-in-Hawaiʻi>.

<sup>150</sup> Ibid.

## 2.5 HYDROMODIFICATION

### The Anthropocene

According to *Climate Change 2013*, a compilation of reports by the Intergovernmental Panel on Climate Change (IPCC), “science points, with 95% certainty, to human activity as the dominant influence on climate and the environment.”<sup>151</sup> Urbanization began with a shift in how humans and their societies approached their environment. The early humans first approached the environment by moving their communities to the environment’s resources. Foraging, scavenging, and hunting for wild plants and animals were the primary methods in obtaining goods. The survival of the hunter-gatherer society was dependent on the pursuit of water availability and on the observation of seasonal change.<sup>152</sup>

Approximately 10,000 years ago, the hunter-gatherer approach shifted with the advent of agriculture. While Neolithic human societies evolved individually across different timeframes, according to the UN, the earliest evidence of domesticating plants and animals and techniques for production first occurred in the region of Mesopotamia. The idea of an organized social body gradually diffused to other parts: the Nile, Indus, and Hoang-ho Valleys.<sup>153</sup> Agriculture stimulated the establishment of permanent settlements, the domestication of plants and animals, and led to ecosystem enhancement and resource management.<sup>154</sup>

Ecosystem enhancements such as hydrologic manipulation incentivized the sedentary nature of these first settlements.<sup>155</sup> Just as with the ancient Hawaiians, many ancient civilizations like China, Egypt, and Mesopotamia settled within fertile areas and fostered human-nature relationships with their environment. Experimentations in ecosystem manipulations led to improvements in agricultural technology which led to rapid population growth and established urban cities. However, agriculture and population growth are not the only drivers in the rise of urban cities. As settlements spread, local population increased, and

---

<sup>151</sup> Intergovernmental Panel on Climate Change (IPCC), comp., *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Thomas F. Stocker, Dahe Qin, Gian-Kasper Plattner, Melinda MB Tignor, Simon K. Allen, Judith Boschung, Alexander Nauels, Yu Xia, Vincent Bex, and Pauline M. Midgley (Cambridge: Cambridge University Press, 2014), foreword.

<sup>152</sup> Elmqvist, *Urbanization, biodiversity and ecosystem services*, 14.

<sup>153</sup> United Nations, *Patterns of Urban and Rural Population Growth* (New York: United Nations, 1980), PDF, 1.

<sup>154</sup> Ibid., 14-19.

<sup>155</sup> Ibid., 14.

technologies developed, diversity and complexity in the society created a necessity for an urban framework.<sup>156,157</sup> A territorial government, a formalized system of laws, a structured society, and craft specialization made urbanization possible and continue to characterize today's nations.<sup>158</sup>

From the time of the first "urban" settlements up until the 18<sup>th</sup> century, agriculture remained the same and kept the ratio of rural to urban population at equilibrium.<sup>159</sup> However, "*humans' consciousness of their ability to induce change gradually accelerated and created a revolutionary phase*"<sup>160</sup> in approaching the environment. The Industrial Revolution modernized agriculture and caused a boom in commerce, trade, and industry. It also caused select rural settlements to evolve into urban cities.

According to the UN, the urban cities differed from the rural settlements. Urban cities had a multiplicity of functions that are interdependent and generate more functions. An urban city now needed administration, management, legal services, banking, information services, and other vocations.<sup>161</sup> Because these functions were interdependent, they needed to be physically close to each other, prompting the populations to conglomerate. The advantages enjoyed by urbanites such as higher wages, protection, services, education, entertainment, specializations, and exchange of non-agricultural goods<sup>162</sup> led to the migration of hundreds of millions of people from rural settlements to these growing urban cities for employment opportunities, prosperity, and "better" lifestyles. This redistribution of the world's population to concentrated areas directly affected the natural systems of the earth.

### **Effects of Urbanization**

---

<sup>156</sup> Ibid., 16-20.

<sup>157</sup> United Nations, *Patterns of Urban and Rural Population Growth*, 1.

<sup>158</sup> Ibid., 18.

<sup>159</sup> Leonid Grinin, "The Urbanization and Political Development of the World System: A Comparative Quantitative Analysis," in *History & Mathematics: Historical Dynamics and Development of Complex Societies*, by Andrey Korotayev, ed. Peter Turchin (Moscow: KomKniga/URSS, 2006), 131-132, 145.

<sup>160</sup> United Nations, *Patterns of Urban and Rural Population Growth*, 1.

<sup>161</sup> Ibid., 2.

<sup>162</sup> Ibid., 3.

According to the United Nations, the world population in 1800 was at 978 million. The UN uses the year 1800 to demarcate the beginning of the industrial revolution—the major shifting of people from rural to urban areas.<sup>163</sup> The UN estimates that only 2 per cent of the world's population lived in urban areas in 1800. In 1900, 14 per cent (231 million) of 1.65 billion were urbanites, and in 1950, 30 per cent (756 million) of 2.52 billion resided in urban centers all over the world. In 2014, 54 per cent of the world's population resided in urban areas. The population of urban areas is projected to increase to 66 percent by 2050.<sup>164</sup> The ratio of resources and population is imbalanced; the ecological footprint of a city is much larger than the area of the city itself.

Cities became more complex with the development of urban infrastructures like electric systems, waste-water systems, public transport systems, facilitating rapid growth of urban cities and the spread of urbanization.<sup>165</sup> By the 19<sup>th</sup> century, urbanization was affecting a broader regional footprint through complex land development and great construction works such as dams, canals, and pumps.<sup>166</sup> At the end of the twentieth century, the irrigated areas in developed countries reached 123 million acres, but scarcity of land and water stunted the construction of more irrigation infrastructure.<sup>167</sup> For the first time since the beginning of human settlements, urbanization was viewed as a problem.

Cities and populations grew by draining away resources from the surrounding natural environment without returning any equivalent services to the natural system; a disproportionate model of growth. Human societies have overburdened the natural environment to the point that natural systems are deficient in their resiliency and the human societies must compensate.

The problems associated with urbanization are numerous. They are detrimental to the quality of our current city environment and the surrounding natural environment. Cities are

---

<sup>163</sup> United Nations. Department of Economic and Social Affairs. Population Division., *The World at Six Billion*. (Washington, D.C.: Population Division, Dept. of Economic and Social Affairs, United Nations Secretariat, 1999), 5, accessed December 16, 2016, <http://www.un.org/esa/population/publications/sixbillion/sixbillion.htm>.

<sup>164</sup> United Nations Department of Economic and Social Affairs/Population Division, *World Urbanization Prospects: The 2014 Revision* (New York: United Nations, 2015), 7, accessed December 15, 2016, <https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf>.

<sup>165</sup> United Nations, *Patterns of Urban and Rural Population Growth*, 4.

<sup>166</sup> FAO, *The New Generation of Watershed Management Programmes and Projects*, 6.

<sup>167</sup> Phillip Z. Kirpich, *Water Encyclopedia: Science and Issues*, s.v. "Irrigation Management," Irrigation Management in Developed Countries, accessed December 16, 2016, <http://www.waterencyclopedia.com/Hy-La/Irrigation-Management.html>.

increasingly becoming unsustainable and vulnerable to natural phenomena and urban disasters. And while natural occurrences such as tsunamis and forest fires cannot be prevented, the urbanization-induced disasters can be. For human societies to prosper in the future and for cities to thrive in health, the most significant problem that needs addressing is hydromodification.

### **Hydromodification**

Cities depend on freshwater ecosystems to support human recreation, transportation, sanitation, and other daily activities.<sup>168</sup> Since the 1960s, “*large scale projects threaten these valuable ecosystem services such as land resources development for agriculture, energy, mining, forestry, transportation, and residential housing; and water resources development for irrigation, municipal water supply, and flood control. For instance, urban development and efforts to use rivers for transportation, water supply, flood control, irrigation, and power generation often alter flow regimes thus threatening the sustainability of the ecosystem services that rivers and river-fed lakes provide.*”<sup>169</sup> The Environmental Protection Agency (EPA) defines hydromodification as the “alteration of the hydrologic characteristics of coastal and noncoastal waters, which in turn could cause degradation of water resources”<sup>170</sup> to support the population. Irrigation infrastructure leads to land degradation, shortages in water, soil erosion, loss of biota and biodiversity, increase in population, and sprawl.

Urbanization is the most significant reason for hydromodification because it creates impervious surfaces—roads, buildings, sidewalks, parking lots, flood control channels, dams, impoundments—increasing the speed and amount of runoff that flows into bodies of water.<sup>171</sup>

In urbanized areas, storm water runs off too quickly from impervious surfaces, into storm drains and directly into the streams without the opportunity to infiltrate the soil or to evaporate. In combination, the rapidly flowing water from urban areas is unable to carry

---

<sup>168</sup> Elmqvist, *Urbanization, biodiversity and ecosystem services*, 26.

<sup>169</sup> Yusuf M. Mohamoud, Rajbir S. Parmar, and Anne C. Sigleo, *Modeling the Impacts of Hydromodification on Water Quantity and Quality* (Athens, GA: National Exposure Research Laboratory Ecosystems Research Division, 2009), 3, accessed December 16, 2016, [https://www.epa.gov/sites/production/files/2015-07/documents/2009\\_12\\_2\\_basins\\_docs\\_modeling.pdf](https://www.epa.gov/sites/production/files/2015-07/documents/2009_12_2_basins_docs_modeling.pdf).

<sup>170</sup> USEPA, *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (Washington, DC: United States Environmental Protection Agency Office of Water, 1993), 6:90, accessed December 16, 2016, <https://www.epa.gov/nps/guidance-specifying-management-measures-sources-nonpoint-pollution-coastal-waters>.

<sup>171</sup> *Ibid.*, 9.

sediment which alters the stream's stability. The rapid flow of water and lack of sediment causes stream channels to erode and the impervious surfaces transport pollutants.<sup>172</sup>

### **Contributors to Stream Degradation**

Hydromodification is the source of water quality impairment for streams, lakes, estuaries, aquifers, and other water bodies in the United States.<sup>173</sup> The National Water Quality Inventory (NWQI) states that nonpoint source (NPS) pollution from agriculture and urban runoff are among the leading contributors to deteriorating streams. Channelization and habitat alteration follow.<sup>174</sup>

Nonpoint source (NPS) is pollution discharged over a wide land area, not from one particular location.<sup>175</sup> USEPA defines nonpoint source pollution as “the pollution of our nation's waters caused by rainfall or snowmelt moving over and through the ground.”<sup>176</sup> When the runoff moves across the surface, it picks up soil particles and pollutants like nutrients and pesticides. According to the USGS, NPS is caused by sediment, nutrients, organic and toxic substances originating from land-use activities, which are carried to bodies of water and streams by surface runoff.<sup>177</sup>

Agricultural activities that result in nonpoint source pollution include silviculture, aquaculture, tillage, ploughing, manure spreading, clear-cutting, animal feeding operations, grazing, plowing, pesticide spraying, irrigation, fertilizing, planting, and harvesting.<sup>178</sup> Agricultural activities cause harm to both surface and ground water. Sedimentation carries phosphorus and pesticides that are absorbed by the sediment particles.<sup>179</sup> This causes dysfunction in ecological systems, and may lead to public human health problems. Nitrates

---

<sup>172</sup> USGS, "Runoff (surface Water Runoff)," The USGS Water Science School, accessed December 16, 2016, <https://water.usgs.gov/edu/runoff.html>.

<sup>173</sup> USEPA, *National Management Measures to Control Nonpoint Source Pollution from Hydromodification* (Washington, DC: United States Environmental Protection Agency Office of Water, 2015), 1:2, accessed December 16, 2016, [https://www.epa.gov/sites/production/files/2015-09/documents/hydromod\\_all\\_web.pdf](https://www.epa.gov/sites/production/files/2015-09/documents/hydromod_all_web.pdf).

<sup>174</sup> USEPA, *National Water Quality Inventory: Report to Congress. 2004 Reporting Cycle* (Washington, DC: United States Environmental Protection Agency Office of Water, 2009), 15, accessed December 16, 2016, [https://www.epa.gov/sites/production/files/2015-09/documents/2009\\_01\\_22\\_305b\\_2004report\\_2004\\_305breport.pdf](https://www.epa.gov/sites/production/files/2015-09/documents/2009_01_22_305b_2004report_2004_305breport.pdf).

<sup>175</sup> USEPA, *National Water Quality Inventory*, 10.

<sup>176</sup> USEPA, *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, 1-1.

<sup>177</sup> USGS, *Water Science Glossary of Terms*, s.v. "Non-point Source (NPS) Pollution," accessed December 16, 2016, <https://water.usgs.gov/edu/dictionary.html>.

<sup>178</sup> Edwin D. Ongley, *Control of Water Pollution from Agriculture* (Rome: Food and Agriculture Organization of the United Nations (FAO), 1996), 10, accessed December 15, 2016, <ftp://ftp.fao.org/agl/aglw/docs/idp55e.pdf>.

<sup>179</sup> Ongley, *Control of Water Pollution from Agriculture*, 10.



can leach into the ground water, contaminating a great source of potable water.<sup>180</sup> This is especially important for O‘ahu. On the surface, siltation can occur on the beds of natural waterways, causing loss of habitats, and aquatic spawning grounds.<sup>181</sup> Water quality decreases as eutrophication causes abnormalities in the taste and smell of water.

*“Hydromodification impacts are caused by the combined effects of frequently occurring small storms—like flood impacts.”*<sup>182</sup> Flooding becomes more prevalent as the area of impervious surfaces increase.<sup>183</sup> Flood impacts include increased erosion, unstable stream banks, damages to property and urban infrastructure, and dirty sewage water. And while larger, infrequent storm events cause flood damage<sup>184</sup>, climate change is increasing the frequency of these events. Planners and policy-makers are concerned that Hawai‘i’s current urban infrastructure cannot withstand the impacts.<sup>185,186</sup>

“Dams and impoundments benefit the human societies because they control flooding, generate electric power, and provide irrigation, navigation, recreation, and municipal water needs.”<sup>187</sup> However, adverse environmental impacts outweigh these benefits. “These modifications cause flow alteration, and inundate wetlands and riparian areas past their holding capacities.”<sup>188</sup> Large irrigation projects such as dams, culverts, and impoundments cause erosion and excess sediment. The excess sediment affects the “abundance, diversity, and fitness of aquatic communities.”<sup>189</sup> Sediment can carry pollutants from urban areas into water bodies like mercury which can accumulate in aquatic species, leading to food degradation.

According to the USGS, sewer lines are constructed next to streams to take advantage of the continuous, gradual slopes of the landscape, and follow the path of least resistance.<sup>190</sup> The extensive sewer system that collect human and point source wastes usually leak and add to the pollution of streams<sup>191</sup> because of *blockages, inadequate carrying capacity, leaking pipes, main*

---

<sup>180</sup> Ibid.

<sup>181</sup> Ibid.

<sup>182</sup> CASQA, *Introduction to Hydromodification by the California Stormwater Quality Association* (Sacramento Stormwater Quality Partnership, 2009), 3, accessed December 16, 2016, <http://www.beriverfriendly.net/docs/files/File/HMP/HMPAppendixABC.pdf>.

<sup>183</sup> USGS, "What Is a Watershed?"

<sup>184</sup> CASQA, *Introduction to Hydromodification*, 3.

<sup>185</sup> Townscape, Inc. and Eugene Dashiell, *Ala Wai Watershed Analysis Final Report*, 25.

<sup>186</sup> Army Corps of Engineers, *Ala Wai Canal Project*, 40.

<sup>187</sup> Mohamoud, et al., *Modeling the Impacts of Hydromodification*, 12.

<sup>188</sup> Ibid.

<sup>189</sup> Ibid., 66.

<sup>190</sup> USGS, "The Effects of Urbanization on Water Quality: Sewage Overflows," The USGS Water Science School, accessed December 16, 2016, <https://water.usgs.gov/edu/urbansew.html>.

<sup>191</sup> William Whipple, *Stormwater Management in Urbanizing Areas* (Englewood Cliffs: Prentice-Hall, 1983), 4.

*breaks, and power outages at pumping stations often lead to sewage overflows into nearby streams.*"<sup>192</sup> There are three types of sewer systems. Storm sewers carry storm runoff from streets, parking lots, and roofs through pipes and ditches, which eventually empty directly into the streams. Sanitary sewers carry raw sewage from homes and businesses to waste-water treatment facilities. Combined sewers carry both.<sup>193</sup>

According to the EPA, sanitary sewers overflow when the pipes are blocked, the line breaks, pumping stations malfunction, or improper sewer design.<sup>194</sup> Combined sewer overflows occur during heavy rainfall and storm water invades sewer lines.<sup>195</sup> The raw sewage carries bacteria, viruses, parasitic organisms, which all lead to diseases that range from mild to life-threatening.<sup>196</sup> Wetlands can actually remove or convert large quantities of pollutants naturally.<sup>197</sup> However, the amount of human waste that urban areas release would overwhelm nature's filtration system. Treatment plants compensate and reduce pollutants in wastewater to a level our current environment can handle.<sup>198</sup>

It is important to keep sewer water away from our streams. If water treatment is inadequate, drinking water may contain sufficient numbers of parasites to cause illness. Waterborne pathogens can be transmitted to people when they consume untreated or inadequately treated water. Two protozoans that are found in drinking water are *Giardia* and *Cryptosporidium*.<sup>199</sup> The consumption of these parasites can lead to severe problems of the digestive system, which can be life-threatening to everyone, especially the very young, very old, or those with damaged immune systems.

Streams and rivers are also important habitats to many organisms within varied ecosystems. A habitat is the combination of food, water, and cover needed by species to survive and reproduce.<sup>200</sup> Channel modification activities such as clearing of riparian zones, dredging, widening, and straightening, or indirect modifications caused by flow alteration<sup>201</sup>

---

<sup>192</sup> USGS, "The Effects of Urbanization on Water Quality: Sewage Overflows."

<sup>193</sup> Ibid.

<sup>194</sup> USEPA, "Sanitary Sewer Overflows (SSOs)," National Pollutant Discharge Elimination System, accessed December 16, 2016, <https://www.epa.gov/npdes/sanitary-sewer-overflows-ssos>.

<sup>195</sup> USGS, "The Effects of Urbanization on Water Quality: Sewage Overflows."

<sup>196</sup> USEPA, "SSOs."

<sup>197</sup> Hammer, *Constructed Wetlands for Wastewater Treatment*, 12.

<sup>198</sup> USGS, "Wastewater Treatment Water Use," The USGS Water Science School, accessed December 16, 2016, <https://water.usgs.gov/edu/wuww.html>.

<sup>199</sup> USGS, "The Effects of Urbanization on Water Quality: Waterborne Pathogens," The USGS Water Science School, accessed December 16, 2016, <http://water.usgs.gov/edu/urbanpath.html>.

<sup>200</sup> Hammer, *Constructed Wetlands for Wastewater Treatment*, 108.

<sup>201</sup> USEPA, *National Measures to Control Nonpoint Source Pollution from Hydromodification*, 1-1.

lead to loss of in-stream and riparian habitat and ecosystem benefits, including natural corridors for species movement and conditions for growth and reproduction.<sup>202</sup> Modified waterways collect unsanitary discharge, threatening the biotic integrity of the habitats. The threat in habitats are particularly important in island systems because of their biodiversity and the fragile nature of isolated biomes that took millions of years to evolve.<sup>203</sup>

Biodiversity is high in clean streams ecosystems. Hydromodification of a channel can shift the composition of algae, fish, macro-invertebrate populations, and bank or floodplain vegetation<sup>204</sup> leading to a decline in fish diversity, and the introduction of species that don't usually belong are adverse effects of habitat alteration. In 1979, 22 out of the 41 endangered fish in the United States are dependent on wetlands or found in freshwater habitats.<sup>205</sup> According to a 2012 article published in *BioScience*, "*future fish extinctions in America are estimated to range from 53 to 86 species by 2050*"<sup>206</sup> because of pollution and as many as "83% of listed endangered plants are at risk."<sup>207</sup>

Ecosystem services are both the benefits of humans from ecosystems and the capacity of these natural systems to provide said benefits.<sup>208</sup> These services are associated with sustaining the city. According to UNEP, cities occupy 3% of the earth's land surface, but we consume 75% of the world's natural resources, and produce 50% of the global waste.<sup>209</sup> About 70% of freshwater diversion is applied to enhance food provision.<sup>210</sup> Cities consume tremendous amounts of resources and thus generate large amounts of waste and emission, which degrade the ecosystems. Clean air, safe drinking water, and protection from climate change effects are all highly relevant to human development in cities, and ecosystems provide these. *The false dichotomy between environment and development is nowhere as easy to disprove as in cities.*<sup>211</sup>

---

<sup>202</sup> USEPA, *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, 6-5.

<sup>203</sup> Elmqvist, *Urbanization, biodiversity and ecosystem services*, 48.

<sup>204</sup> USEPA, *National Measures to Control Nonpoint Source Pollution from Hydromodification*, 2-8.

<sup>205</sup> Hammer, *Constructed Wetlands for Wastewater Treatment*, 115.

<sup>206</sup> Noel M. Burkhead, "Extinction Rates in North American Freshwater Fishes, 1900-2010," *BioScience* 62, no. 9 (September 2012): 806, <http://www.jstor.org/stable/10.1525/bio.2012.62.9.5>.

<sup>207</sup> *Encyclopedia.com*, s.v. "Habitat Alteration," 2009, section goes here, accessed December 16, 2016, <http://www.encyclopedia.com/environment/energy-government-and-defense-magazines/habitat-alteration>.

<sup>208</sup> Elmqvist, *Urbanization, biodiversity and ecosystem services*, 509.

<sup>209</sup> UNEP, *Cities and Buildings UNEP Initiatives and Projects* (Milan: UNEP-DTIE Sustainable Consumption and Production Branch), accessed December 16, 2016, [http://www.unep.org/SBCI/pdfs/Cities\\_and\\_Buildings-UNEP\\_DTIE\\_Initiatives\\_and\\_projects\\_hd.pdf](http://www.unep.org/SBCI/pdfs/Cities_and_Buildings-UNEP_DTIE_Initiatives_and_projects_hd.pdf).

<sup>210</sup> Elmqvist, *Urbanization, biodiversity and ecosystem services*, 510.

<sup>211</sup> *Ibid.*, vi.

According to several sources, over half of the world's population resides in cities, and an increase of 70-80% is projected for 2050.<sup>212</sup> The prosperity of the urban setting, in terms of employment, environment, health, education, and overall quality of life not only depend on how urbanization is planned and managed, but also how ecosystems and the services they provide are preserved and protected.<sup>213</sup>

Figure 15: Ecosystem services diagram  
Source: ICUN<sup>214</sup>

---

<sup>212</sup> United Nations, *World Urbanization Prospects: The 2014 Revision*, 2-7.

<sup>213</sup> UNEP, *Cities and Buildings*, 1, 11.

<sup>214</sup> International Union for Conservation of Nature, Ecosystem services diagram, digital image, Fresh Water Watch, February 9, 2017, accessed February 26, 2017, <https://www.iucn.org/news/commission->

### **Context and Significance**

According to the EPA, hydromodification is the leading source of water quality impairment for streams, lakes, estuaries, aquifers, and other water bodies in the United States. For human societies to prosper in the future and for cities to thrive in health. Currently, 64% of Hawai'i streams have become impaired by pollution, 98% of drinking water is sourced from the ground, and our island population continues to increase, while fresh water supply is decreasing.<sup>215</sup> Approximately 1.4 million people currently reside in Hawai'i today, and the island is made up of these stream networks in watersheds. Hydromodification and the effects associated with it are detrimental to the prosperity of the entire state of Hawai'i, and not just the Ala Wai Watershed.

---

environmental-economic-and-social-policy/201702/step-sustainability-maes-mapping-and-assessment-ecosystem-services-european-cities-and-italy.

<sup>215</sup> State of Hawai'i Department of Agriculture, "History of Agriculture in Hawai'i."

## 2.6 LANDSCAPE INFRASTRUCTURE

*“There are risks and costs to a program of action, but they are far less than the long-range risks and costs of comfortable inaction.”- John F. Kennedy*

### **Concepts from Landscape Ecology**

According to Dramstad, Olson, and Forman, the landscape is a living system that exhibits three characteristics. Structure, which is the spatial pattern or arrangement of landscape elements, function, which is movement or flow of organisms through the structure, and change, which is the alteration or dynamics of spatial pattern over time.<sup>216</sup> “The structure pattern of all landscapes is composed of patches, corridors, and edges – elements that are used as the “handles for comparing different landscapes” or handles for uniqueness, and to develop general principles about the landscape.”<sup>217</sup> Green corridors, stepping stones, types of edges, patches of natural vegetation, and interconnected systems of small patches within a landscape are indispensable principles to the landscape’s infrastructure.

Patches are areas remaining from an earlier time, introduced new areas of development, disturbed areas like burned areas or regions devastated by storms, or environmental resources like wetlands.<sup>218</sup> “Large patches of natural vegetation are the only structures in a landscape that protect aquifers and interconnected stream networks, sustain species and provide the necessary near-natural disturbance regimes.”<sup>219</sup> Small patches across the landscape act as stepping stones, and also serve to support ecological systems.<sup>220</sup>

Edges are the outer portions of patches where the environment differs from being transitional spaces. The shapes of patches can be manipulated to accomplish an ecological function or objective, creating a rich opportunity to use the transition zone—the edge. The edge should act as a filter, to dampen the influence of surrounding patch interiors. Hard edges create movement along it. Soft curve edges create movement across it.<sup>221</sup>

Corridors and connectivity become necessary in light of the dynamic processes of patches. Landscape connectivity in the form of green corridors and stepping stones enhance

---

<sup>216</sup> Dramstad, et al., *Landscape Ecology Principles*, 14.

<sup>217</sup> Ibid.

<sup>218</sup> Ibid., 19.

<sup>219</sup> Ibid., 22.

<sup>220</sup> Ibid.

<sup>221</sup> Ibid., 27-32.

biodiversity. Streams or river systems are significant corridors in a landscape. Maintaining the ecological integrity in the face of hydromodification is a challenge and opportunity. Corridors can also act as barriers between ecosystems. An example of such are roadways and canals.<sup>222</sup>

Landscape ecology principles such as vegetated green corridors, stepping stones, types of edges, patches of natural vegetation, and interconnected systems of small patches across the landscape contribute to the landscape's infrastructure, and are indispensable. According to Dramstad, Olson, and Forman, "no known or feasible alternative exists for providing the many ecological benefits that these principles and patterns provide."

### **Nature's Infrastructure**

Man-made built infrastructure like dams and impoundments will continue to be developed as the primary solution to flooding problems. However, investing in natural infrastructure can help to reduce or avoid economic, and ecological costs, while still providing the necessary water services. These services will not only mitigate flood damage, but deliver quality water to the urban environment.<sup>223</sup>

Natural ecosystems like rainforests and wetlands provide essential services to the urban setting. The natural ecosystems provide provisioning, regulating, habitat, and cultural services. "Provisioning services are the products directly obtained for human use such as food, fresh water, wood, fiber, genetic resources and medicines. Regulating services are defined as the benefits derived from the regulation of ecosystem processes and natural phenomena such as climate regulation, natural hazard regulation, water purification and waste management, pollination or pest control. Habitat services highlight the importance of ecosystems to provide habitat for migratory species and to maintain biodiversity. Cultural services include non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values."<sup>224</sup> Such ecosystem services directly service cities—businesses, communities, neighborhoods, and homes—from regulating water quality and availability, to flood control, to the food on the table. The water-related ecosystem services

---

<sup>222</sup> Ibid., 35-40.

<sup>223</sup> Todd Gartner, ed., *Natural Infrastructure: Investing in Forested Landscapes for Source Water Protection in the United States*, vol. 2 (2013), 11, accessed December 16, 2016, <http://www.wri.org/publication/natural-infrastructure>.

<sup>224</sup> Millennium Ecosystem Assessment (Program), *Ecosystems and Human Well-being: Synthesis* (Washington, DC: Island Press, 2005), 7, 39-40.

provided by the watershed—forests, flatlands, wetlands, and working lands— are known as “natural infrastructure.”<sup>225</sup>

Natural infrastructure, also called green infrastructure, has been defined by the EPA as “a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits.”<sup>226</sup> Watersheds are natural infrastructures. The uplands store infiltration, treat the water, and prevent erosion with forestation. Riparian flood plains buffer flood water while stream networks convey quality water. Wetlands mitigate pollutants and sediment, filter water, hold, and store water, and coral reefs protect coastal habitats. According to the EPA, “the gray water system, conventional piped drainage, and water treatment systems, are designed to move urban storm water away from the built environment.”<sup>227</sup> Natural infrastructure can “replace, augment, or complement”<sup>228</sup> the gray water system because it “reduces and treats storm water at its source while delivering environmental, social, and economic benefits to the built and natural environment.”<sup>229</sup>

The difference between built and natural infrastructure is man-made infrastructure focuses on removing storm water away from the site as fast as possible and natural infrastructure focuses on infiltrating storm water on-site. Storm water runoff is the primary cause of water pollution in urbanized areas. Storm water in natural areas gets filtered by plants and infiltrates directly into the soil. According to the EPA, civil engineers have focused and become comfortable with designing gray infrastructure such as pipes, tanks, pumps for centuries to speedily manage and convey storm water in densely-populated and developed urban areas. Therefore, there is less engineering experience with natural infrastructure technologies as compared to “traditional gray” infrastructure.<sup>230</sup> However, “green” technologies are gaining recognition because they have less impact on the environment than concrete and steel. Moreover, natural infrastructure would be less disruptive to the landscape’s

---

<sup>225</sup> Gartner, *Natural Infrastructure*, 10.

<sup>226</sup> USEPA, “What Is Green Infrastructure?” Green Infrastructure, accessed December 16, 2016, <https://www.epa.gov/green-infrastructure/what-green-infrastructure>.

<sup>227</sup> Ibid.

<sup>228</sup> Jonathan Lautze, *Key Concepts in Water Resource Management: A Review and Critical Evaluation* (London: Routledge, 2014), 116.

<sup>229</sup> USEPA, “What Is Green Infrastructure?”

<sup>230</sup> Michelle Simon, Michael Borst, and Thomas O'Connor, *Green Infrastructure for Stormwater Control: Gauging Its Effectiveness with Community Partners, Summary of EPA GI Reports* (Washington, DC: U.S. Environmental Protection Agency, 2015), 11, accessed December 16, 2016, <http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NE3S.txt>.



hydrology because the intent of the infrastructure is to prioritize storm water infiltration rather than channeling it away from the site.<sup>231</sup>

Rain falling on impervious surfaces such as streets, and parking lots in cities and their suburbs is water that should be infiltrating into the soil and entering the groundwater system, but does not. Many of the soils in urban areas “have been disturbed, altered, or relocated and most have been compacted which reduces their ability to infiltrate water.”<sup>232</sup> Instead, it becomes excess surface water, causing flooding, erosion, damaging habitats, and often, overwhelms the man-made drain systems. Stormwater in urbanized areas gets redirected into the drain system through gutters, storm sewers, and other collection systems before entering receiving water bodies. The stormwater also carries trash, bacteria, heavy metals, and other pollutants from the urban areas into the receiving waters. Rain that falls in natural, undeveloped areas, the water is directly absorbed and filtered by plants and soil. The excess water that runs along the surface is also cleaner and unaffected by human induced pollutants.

Figure 16: Diagram of urban water infrastructure.

Source: Mississauga<sup>233</sup>

There are many technologies that make up natural infrastructure. In general, the infrastructure uses vegetation, soils, and other elements and practices—characteristics of a natural landscape—to mimic nature. By restoring some of the natural processes characteristic of a watershed within an urban area, the hybridized infrastructure can provide habitat, flood

---

<sup>231</sup> Ibid., 11.

<sup>232</sup> Ibid., 15.

<sup>233</sup> Mississauga, "Stormwater Drainage System," digital image, Stormwater Program, accessed December 10, 2016, <http://www.mississauga.ca/portal/stormwater>.

protection, clean water, and at the same time, create a healthy urban setting. According to the EPA, “at the city or county scale, green infrastructure is a patchwork of natural areas that provide ecosystem services. At the neighborhood or site level, its stormwater management systems that mimic nature soak up and store water.”<sup>234</sup>

### **The Ahupua‘a’s Missing Infrastructure**

Water is the backbone of the natural and urban environment. The ahupua‘a had three ecological zones that were naturally organized by the network of streams and bodies of water: the wao akua (uplands) rainforest, the wao kanaka (midlands) agriculture fields and settlement, and kaha kai (coastal land) marshes and aquaculture lands. The wao akua and the kaha kai functioned to filter the water in its path to the human settlements and its return to the akua (gods). The human settlements in the wao kanaka also prioritized the quality of water that flows into the kaha kai. Today, the upland rainforests are part of the Conservation District and the midlands are urbanized. The stream network from mauka to makai does not provide much ecosystem services and the coastal lands do not function as wetlands anymore. The waterfront is prized for real estate because people are drawn to the water’s edge. The urbanization of the islands’ waterfronts created a hole in the ecological zone and the water filtration cycle.

### **Applicable Infrastructure**

Forests have a favorable effect on water resources. According to Gartner, Mulligan, Schmidt, and Gunn, forests (1) have sturdy, long-lived roots that help to anchor soil against erosion and (2) have multiple layers of thick canopy and vegetation to slow falling rain and reduce its erosive force. Forests areas (3) have more interception, greater photosynthetic area, meaning higher evapotranspiration. Forested areas (4) promote infiltration of water into the soil, (5) provide a barrier that slows downslope water movement, and (6) minimize sediment and pollutant delivery to water systems through subsoil, which (7) gives ample opportunity for nutrient uptake by plants and microbes in the soil.<sup>235</sup>

According to *Natural Infrastructure*, “the favorable characteristics of forests coupled with very high infiltration rates of forest soils minimize storm flow and render erosion unlikely

---

<sup>234</sup> USEPA, "What Is Green Infrastructure?"

<sup>235</sup> Gartner, *Natural Infrastructure*, 32-34.

for all but the most intense storm events.”<sup>236</sup> Cutting trees reduces transpiration and causes an increase in soil saturation, which causes greater surface water flow, leading to flooding. When forest vegetation is cleared, the effects on water yield and peak storm water flows are commensurate with the scope and scale of clearing. “As forests are converted to other land uses or are unnaturally disturbed, the benefits from forests will diminish, putting communities at risk of food, drought, higher cost of treatment, and greater incidence of drinking water contamination.”<sup>237</sup>

According to the United States Forest Service, urban watershed forestry is a practice that draws from multiple disciplines, including forestry, hydrology, engineering, landscape architecture, mapping, planning, and soil science.<sup>238</sup> The magnitude of impacts due to the loss of green space in urban watersheds, such as increased runoff and impervious cover, demonstrates the vital role of forestry in urban watershed management. Cappiella, Schueler, and Tiffany also state that past approaches to restoring urban watersheds that have relied on engineering solutions have failed to protect and restore urban streams. Therefore, many practitioners in the engineering community are now turning to vegetation and natural systems as a critical part of the solution.<sup>239</sup>

Urban watershed forestry sets “*watershed-based goals for managing the urban forest as a whole rather than managing forest resources on a site-by-site and provides strategies for incorporating forests into urban watershed management.*”<sup>240</sup> The integration of urban forestry techniques into urban watershed management places importance on trees and forests which help to preserve and protect water resources.<sup>241</sup> Urban watershed forestry takes a new approach to watershed protection and restoration by systematically tracking and managing forest cover at the watershed level. The basic aim of urban forestry is to reduce forest loss and maximize forest gains over time.<sup>242</sup>

---

<sup>236</sup> Ibid., 33.

<sup>237</sup> Ibid., 36.

<sup>238</sup> Karen Cappiella, Thomas R. Schueler, and Tiffany Wright, *Urban Watershed Forestry Manual : Part 1/ Methods for Increasing Forest Cover in a Watershed* (Newtown Square, PA: US Department of Agriculture, 2005), i.

<sup>239</sup> Ibid.

<sup>240</sup> Ibid., 1.

<sup>241</sup> Ibid.

<sup>242</sup> Ibid., 4.

Figure 17: Water and nutrient cycles in the rainforest.

Source: BBC<sup>243</sup>

Constructed wetlands are defined as “a designed and man-made complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for human use and benefit.”<sup>244</sup> They are complex systems with many design parameters. Constructed wetlands that want to manage and filter water before it enters a receiving body of water are usually in the form of marshes.<sup>245</sup> According to Hammer, constructed wetlands have five principal components: (1) substrates with various rates of hydraulic conductivity, (2) plants adapted to water-saturated anaerobic substrates, (3) water flowing in or above the surface of the substrate, (4) invertebrates and vertebrates, (5) and an aerobic and anaerobic microbial population.<sup>246</sup>

Wetland plants have the unique ability to transport oxygen to support their roots growing in anaerobic substrates. The plants appearing in the constructed wetlands “*should be naturally occurring plants which are adapted to local climate and soil conditions and are much more likely to*

---

<sup>243</sup> BBC, "Rainforest Water and Nutrient Cycles," digital image, Bitesize, accessed December 10, 2016, [http://www.bbc.co.uk/schools/gcsebitesize/geography/ecosystems/tropical\\_rainforests\\_rev2.shtml](http://www.bbc.co.uk/schools/gcsebitesize/geography/ecosystems/tropical_rainforests_rev2.shtml)

<sup>244</sup> Hammer, *Constructed Wetlands for Wastewater Treatment*, 12.

<sup>245</sup> Ibid., 13.

<sup>246</sup> Ibid., 14.

*succeed and provide treatment.*<sup>247</sup> In wetland marshes, it is beneficial to have different types of plants, even though the three main plants used for treatment systems—cattail, bulrush, and reeds—tend to compete for dominance with other plants.<sup>248</sup>

Figure 18: How wetlands work.  
Source: Ivy Ferguson<sup>249</sup>

Constructed wetlands are very applicable in dealing with water pollution problems, just like their natural counterpart does. Wetlands naturally occur at lowland levels, so they are accustomed to different pollutants and sediments found in the run off they receive from their upper sources. According to Hammer, “depending on the degree of pollution in the water, constructed wetlands may remove or modify the toxin in the water and self-maintain or may need to be regulated by plant harvesting, incineration, or other disposal methods to keep the system working.”<sup>250</sup>

Constructed wetlands, unlike the rainforests, which are crucial, can be appended to, or replace conventional engineered water treatment or filtration systems. They are (1) inexpensive systems, (2) for the most part, self-maintaining, (3) easy to operate, (4) adequate in treating wastewater, (5) tolerant of hydrologic fluctuations, (6) tolerant of contamination, (7) provide human recreational green space, (8) and provide estuarine habitat for wildlife. However,

---

<sup>247</sup> Ibid., 15.

<sup>248</sup> Ibid.

<sup>249</sup> Ivy Ferguson, "How Wetlands Work," digital image, Environment Tobago, accessed December 10, 2016, <http://www.environmenttobago.net/?q=node/32>.

<sup>250</sup> Hammer, *Constructed Wetlands for Wastewater Treatment*, 16.

constructed wetlands (1) usually require large areas, (2) are so dynamic and complex and there is not enough understanding of their processes, (3) often require many months or several years before optimal efficiency is achieved, (4) and there are possible problems with pests.<sup>251</sup> Constructed wetlands provide a solution to mitigate water pollution problems alongside man-made infrastructure that is already embedded in the urban fabric. Constructed wetlands are the alternative to using a natural wetland to treat human pollution. It is the humans' duty to compensate and protect existing natural wetlands and preserve them.<sup>252</sup>

**Context and Significance:** In addressing the problems of hydromodification in the Ala Wai Watershed, the focus of applied infrastructure will be to mimic nature to filter, soak up, and storewater on site and minimize the amount of surface water being taken off-site. The two parts of the ahupua'a's ecological zones that played roles in filtering, sponging, and holding water were the upland rainforest and the coastal wetlands. Natural infrastructure in the form of re-vegetating or re-foresting patches to extend the upland rainforests within the landscape, and re-constructing wetlands on transitionary edges can perform to minimize the amount of surface water that flows through the landscape and clean the water from urban areas before they enter receiving waters.

---

<sup>251</sup> Ibid., 16-17.

<sup>252</sup> Ibid., 18.

### III SITE

### 3.1 PHYSICAL

Figure 19: The Hawaiian Islands.  
Source: By Author

#### **Geography**

The Hawaiian Islands formed as early as 70 million years ago. Hawai'i has over 130 islands and atolls totaling 6,423 square miles and are spread out over 1,500 miles across the Pacific Ocean. The eight main islands are Hawai'i, Maui, O'ahu, Kaua'i, Moloka'i, Lāna'i, Ni'ihau, and Kaho'olawe, are at the southeastern end of the archipelago. They are the youngest in a chain of volcanoes called the Hawaiian Emperor Seamount Chain. The tectonic plate beneath much of the Pacific Ocean continually moves northwest, and the hot spot remains stationary, slowly creating new volcanoes. Currently, the hotspot is located on Hawai'i (Big Island). There are older islands to the northwest of Kaua'i that extend from Nihoa to Kure Atoll which have been eroded away by wind and rain over several millions of years.

The Hawaiian Islands are the most isolated archipelago in the world, located 2,000 miles southwest of the continental United States. Because of this isolation, the ecosystems on the volcanic islands are unique. The ancient isolation once allowed species to arrive solely by wings, water, and wind, producing endemic flora and fauna. The complexity of the Hawaiian



Islands' geography created a diversity of plants, animals, birds, and invertebrates. As such, Hawai'i is recognized as a "biological hotspot for its biodiversity and the vulnerability of its flora and fauna to habitat loss and alteration, invasive species, and natural disasters."<sup>253</sup> Each element within the endemic ecosystem is integral to the entire system.

Figure 20: Orographic precipitation  
Source: Encyclopedia Britannica<sup>254</sup>

The steep and varying elevations of Kaua'i, O'ahu, Maui, Hawai'i, and Moloka'i interact with the easterly trade winds that are present year-round. Clouds are always present in Hawai'i but are confined by the mountains<sup>255</sup>, separating select islands with high mountain elevations into windward (wet), and leeward (dry) sides. This is called orographic precipitation. Orographic precipitation allows for a gradient of climates and microclimates. The encyclopedia states that "orographic precipitation is produced when moist air is lifted as it

---

<sup>253</sup> DLNR, *Hawai'i Statewide Comprehensive Outdoor Recreation Plan 2015 Update*, 12.

<sup>254</sup> Encyclopedia Britannica, "Orographic Lift," digital image, Britannica, July 20, 1998, accessed December 10, 2016, <https://www.britannica.com/science/orographic-precipitation>.

<sup>255</sup> DLNR, *Hawai'i Statewide Comprehensive Outdoor Recreation Plan 2015 Update*, 12.

moves over a mountain range. As the air rises and cools, orographic clouds form and serve as the source of the precipitation, most of which falls upwind of the mountain ridge. Some water also falls a short distance downwind of the ridge and is sometimes called spillover. On the lee side of the mountain range, rainfall is usually low, and the area is said to be in a rain shadow. Heavy precipitation typically occurs upwind of a prominent mountain range that is oriented across a prevailing wind from a warm ocean.”<sup>256</sup>

Figure 21: Freshwater sources on O‘ahu.  
Source: Rainfall Atlas of Hawaii<sup>257</sup>

While it is largely unknown how much rain fell on the mountain ranges of the Hawaiian Islands over millions of years, recent observations indicate that the upper portions of the Ko‘olau Mountains in O‘ahu receive an average of more than 158 inches per year. The lower

---

<sup>256</sup> Encyclopædia Britannica, *Encyclopædia Britannica*, s.v. "Orographic Precipitation," July 20, 1998, accessed December 16, 2016, <https://www.britannica.com/science/orographic-precipitation>.

<sup>257</sup> Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delaparte, 2013: Online Rainfall Atlas of Hawai‘i. *Bull. Amer. Meteor. Soc.* 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

portions on the leeward side receive an average of 25 inches per year. Two billion gallons of rainwater fall on the island of O'ahu, whereby most of it falls on the peaks of the Ko'olau, instead of the Wai'anae Range. The highest point of the Ko'olau is Pu'u Konahuanui which stands at 3,150 feet. This year, the Rainfall Atlas of Hawai'i recorded 120 inches of rain on this peak.<sup>258</sup> The Hawaiian Islands boast the highest recorded annual average rainfalls in the world.<sup>259</sup> Rain is essential not only to the soil development, the distribution of streams and wetlands, and flora and fauna, but also to the people.

---

<sup>258</sup> Ibid.

<sup>259</sup> DLNR, *Hawai'i Statewide Comprehensive Outdoor Recreation Plan 2015 Update*, 12.

## 3.2 PEOPLE & MYTHS

### Arrival

Although no one knows exactly when the first colonizers arrived in Hawai‘i, per archaeological evidence and oral tradition, the earliest inhabitants of the Hawaiian Islands were said to have arrived in 300 CE. It is speculated that Polynesians explored the Hawaiian Islands and settled on O‘ahu, at the Windward side in Waimanalo and Kailua’s Kawai Nui Marsh, 1800 years ago because it appeared “the most fertile.”<sup>260,261</sup> Other sources say that the Hawaiian Islands were settled before the Polynesians by the menehune, mythical little people who built heiaus and fishponds.<sup>262</sup> The settlers were skilled with agriculture, horticulture, fishing. As such they would choose an appropriate landscape to make use of their skills. According to Patrick Kirch, “to colonizing Polynesians with a horticultural economy augmented by fishing, the key environmental factor affecting settlement were the distribution of arable alluvial and colluvial soils, rainfall, streamflow, and coral reefs.”<sup>263</sup> Of the Hawaiian Islands, O‘ahu, Kaua‘i, and Moloka‘i had the geological landforms and soil development that favored wetland agriculture that the settlers were looking for.<sup>264</sup>

### Agricultural Settlers

The agricultural settlers evolved alongside the endemic ecosystem of the Hawaiian Islands and synchronized their social organization with the system. The estuaries and streams were adapted into fishponds by the settlers. Eventually, the landscape was organized. There is a general belief that the natural organization of settler communities along the streams is the foundation for the complex socioeconomic, geologic, and climatic subdivision of land, which dictated and was dictated by community governance attributed to shared water usage. “David Malo, a Hawaiian historian theorizes that in ancient Hawai‘i, all the people started out as ali‘i, and only after several generations that a division was made into commoners and chiefs.”<sup>265</sup>

---

<sup>260</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 11-12.

<sup>261</sup> Samuel Manaiakalani, Kamakau, Mary Kawena, Pukui, and Dorothy B. Barrows, *Tales and Traditions of the People of Old / Nā Mo‘olelo O Ka Po‘e Kahiko* (Honolulu: Bishop Museum Press, 1991), 108.

<sup>262</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 12.

<sup>263</sup> Patrick Vinton Kirch and Marshall Sahlins, *Anahulu : The Anthropology of History in the Kingdom of Hawai‘i* (Chicago: University of Chicago Press, 1992), 7.

<sup>264</sup> Ibid., 5.

<sup>265</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 16.

However, there is also the romanticized and mythic belief in the Hawaiian creation story that sets the backdrop for an indigenous landscape division.

Figure 22: Papa and Wakea  
Source: Solomon Enos<sup>266</sup>

**Myths.** According to the *Kumulipo*, Wākea, Father Sky, and Papahānaumoku, Mother Earth, or Papa for short, who created the Hawaiian Islands chain, had a beautiful daughter named Ho‘ohokukalani, whose name means “the making of stars in the heavens.” Wākea and Ho‘ohokukalani produced a son, but it was stillborn. They called the child Hāloa, meaning “eternal breath” and buried him on the eastern side of their home, the side where the sun rose. The goddess Ho‘ohokukalani grieved, watering her child’s grave with tears. Eventually, a plant grew on Hāloa’s grave. The plant had a long stalk and heart-shaped leaves that quivered in the wind. The gods called this plant Hāloanakalaukapalili, the first kalo plant.

---

<sup>266</sup> Solomon Enos, "Papa and Wākea," digital image, Pinterest, accessed December 10, 2016, <https://www.pinterest.com/pin/180425528793370324/>.

Figure 23: Haloa  
Source: Maggie T. Sutrov<sup>267</sup>

Ho‘ohokukalani gave birth to a second son and named him Hāloa in honor of his older brother, the kalo. Hāloa became the first Hawaiian person. The creation story tells of our genealogic relation to the kalo, the ‘āina, and the rest of the natural world. Thus, the ancient Hawaiians held a deep reverence and strong sense of responsibility towards the natural world.

---

<sup>267</sup> Maggie T. Sutrov, "Haloa," digital image, Island Breath, January 9, 2008, accessed December 10, 2016, <http://www.islandbreath.org/2008Year/01-farming/0801-01SaveHaloa.html>.

They saw themselves as kin of the plants and animals. The landscape of ancient Hawai'i was a clear illustration of the intrinsic and filial relationship between nature and man.

Figure 24: Landscape identity in relation to the creation story.  
Source: By Author

### 3.3 AHUPUA‘A

The ancient Hawaiians followed a complex system of land division that stemmed from their creation myth. This allowed for the people, as a collective entity, to experience a profound connection with nature. They believed they were born from nature and they realized their interdependency with each other. Resource usage was a shared privilege and responsibility, and the Western concept of private property was unknown and unheard of. But to efficiently manage the resources available, the landscape was subdivided into hierarchical levels related to the social system. The ancient Hawaiian social system was ordered by a strict caste system that divided the elite and the commoners. This division was fundamental in determining and managing resource allocation. Even if the political system was rigid, this system put a grave importance on the protection of the natural ecosystems.

The mukupuni was the whole island. It was controlled by the highest chief, who held it in trust for the entire population. The moku is the largest subdivision within a mukupuni. It was ruled by lieutenant chiefs. Within the moku were ahupua‘a, which were managed by minor chiefs and within each ahupua‘a would be several ‘ili typically stewarded by a group of families.

Each ahupua‘a had its own name and carefully fixed boundary lines. Often, the markers were natural features such as large rocks, a line of trees, or even the home of a particular bird. A typical ahupua‘a was a long strip of land, wedge-shaped, running from the uplands to the sea. It was narrow at the mountain summit and becoming wider as it runs down the valley and into the sea to the edge of the reef. The size of the ahupua‘a depended on the resources of the area and how efficient they were in agricultural systems. Poorer agricultural regions, which were characterized by the lack of good soil, streams and estuaries, were grouped to create larger ahupua‘a to compensate for the lack of natural abundance. An abundant ahupua‘a was characterized as having all climate zones and economic exploitation zones. This ensured that each division could be self-sufficient.



Figure 25: Conceptual ahupua‘a.  
Source: Kamehameha Schools<sup>268</sup>

The most important aspect of the ahupua‘a was wai (water). Water from the upland forests was thought to be from the wao akua (the realm of the gods) which were given to flow down the ahupua‘a to the wao kanaka (the realm of the humans) where it sustained life. The ahupua‘a is a watershed—a basin-like landform that carries water "shed" from the land after precipitation. Drop by drop, water is channeled into soils, ground waters, creeks, and streams,

---

<sup>268</sup> Kamehameha Schools, Conceptual ahupua'a, digital image, Kumukahi.org, accessed December 10, 2016, [http://www.kumukahi.org/units/ka\\_honua/onaepuni/ahupua'a](http://www.kumukahi.org/units/ka_honua/onaepuni/ahupua'a).

making its way to larger rivers and eventually the sea. The important thing about watersheds is: what we do on the land affects water quality for all communities living downstream.

Figure 26: The water as a parti through an ahupua‘a.  
Source: Edited by Author<sup>269</sup>

---

<sup>269</sup> Ahupua‘a Agricultural Association of Hawaii, "Ahupua'a," digital image, Kauai University Web Log, January 18, 2013, accessed December 10, 2016, [https://davidlakota.wordpress.com/tag/ahupua‘a-agricultural-association-of-hawaii-aaa/](https://davidlakota.wordpress.com/tag/ahupua-a-agricultural-association-of-hawaii-aaa/).

### 3.4 RISE OF WESTERN AGRICULTURE

#### Unsustainable Practices

In 1828, a French navigator named Bernard Duhaut-Cilly made observations about the poor condition of taro fields as being “*devoured by noxious weeds, irrigation canals are now blocked nearly everywhere; small ponds where taro was grown are totally dried and barren....great expanses of terrain, remnants of what had been dikes and causeways, where now the soil has been so much reduced from its normal elevation that no further witness is needed to prove that in earlier times here stood fields under constant cultivation.*”<sup>270</sup>

This decline should be seen in regard to the political changes brought by foreign proponents of capitalism, the changes in water values and use, new agricultural endeavors, and the loss of indigenous knowledge. The decline in kalo cultivation has been steadily declining since the arrival of Westerners. In 1893, a group of businessmen illegally seized control of the government and its lands with the help of the United States Army. The overthrow of the Hawaiian Kingdom monarchy inflicted physical, social, psychological, ecological and economic change to the islands because the capitalist businessmen now controlled the people, the land and the power in Hawai‘i. Under the new regime, major public works and development projects completely changed and stilled the natural flow of water through the Waikīkī ahupua‘a. Sanitation was often cited as the primary reason to legitimize the redevelopment of prime lo‘i lands into real estate.

The decline of the taro fields beginning in the 1790s was because of the decline in native Hawaiian population through foreign disease. Farmers also abandoned their fields and shifted to working in the sandalwood trade.<sup>271</sup> In the earlier times, lo‘i kalo was estimated to have covered at least 20,000 acres of the six Hawaiian islands. By 1900, only 1280 acres were used for kalo production. By 2007, less than 400 acres are used for kalo production.<sup>272</sup> New food production practices altered the watershed. In 1794, cattle was brought to Hawai‘i from California. Kamehameha immediately placed a taboo on the slaughter of cattle. Many of the derelict taro fields were used for cattle ranching. Some cattle also roamed freely in the upland

---

<sup>270</sup> Kanahele, *Waikiki 100 BC to 1990 AD : An Untold Story*, 112.

<sup>271</sup> Ibid., 113.

<sup>272</sup> Alternative Volume 5, Number 2, 2009, 53.

rainforests and have been a major factor in the loss of forest vegetation.<sup>273</sup> The feral cattle were unchecked throughout the uplands, consuming and trampling vegetation.<sup>274</sup> Demands for sandalwood, firewood, and grazing land continued to degrade upland forests. When the kapu was finally lifted in 1830, cattle were numerous to the hundreds of thousands.<sup>275</sup> Forest destruction above Honolulu was so great that the Nu‘uanu Valley was left bare, stirring concerns about the city’s future water supply.

At the same time, trade in sandalwood increased rapidly in so much that several hundred ships were arriving each year.<sup>276</sup> Sandalwood became the primary export of the kingdom of Hawai‘i. Unfortunately, its production created severe social and environmental damage. Thousands of maka‘āinana were forced to cut, chop, and haul the sandalwood trees by hand. *“There were between two and three thousand men, carrying each from one to six pieces of sandal wood, according to their size and weight. It was generally tied on their backs by bands made of ti leaves, passed over the shoulders and under the arms, and fastened across their breast.”*<sup>277</sup> The indiscriminate logging also wiped out the sandalwood and *“large areas of grassland and dry forest were burned to make the standing or fallen sandalwood easier to find.”*<sup>278</sup> Trading ships also brought non-native songbirds and mosquitoes, introducing foreign maladies such as malaria and pox to Hawai‘i’s human and animal populations.

### **Watershed Preservation in Hawai‘i**

According to Henshaw and Lewis, “the relationship of our forested uplands to a dependable supply of clean water was recognized by Westerners as early as 1860, when sugar

---

<sup>273</sup> Charles P. Stone and Stephen J. Anderson, "Introduced Animals in Hawai‘i's Natural Areas," in *Proceedings of the Thirteenth Vertebrate Pest Conference (1988)*, proceedings of Vertebrate Pest Conference Proceedings, Monterey, California (1988), 137, accessed December 16, 2016, <http://digitalcommons.unl.edu/vpcthirteen/28>.

<sup>274</sup> John Henshaw and James G. Lewis, "The Lessons of History: Making a Case for a National Forest in Hawai‘i," *Forest History Today* Spring/Fall 2011, no. Weeks Act Centennial Issue (2011): 65, accessed December 16, 2016, [http://www.foresthistory.org/publications/FHT/FHTSpringFall2011/National\\_Forest\\_in\\_Hawai‘i.pdf](http://www.foresthistory.org/publications/FHT/FHTSpringFall2011/National_Forest_in_Hawai‘i.pdf)

<sup>275</sup> State of Hawai‘i Department of Agriculture, "History of Agriculture in Hawai‘i."

<sup>276</sup> Kanahele, *Waikiki 100 BC to 1990 AD : An Untold Story*, 104.

<sup>277</sup> Mark Merlin and Dan VanRavenswaay, "The History of Human Impact on the Genus *Santalum* in Hawai‘i," in *Proceedings of the Symposium on Sandalwood in the Pacific April 9-11, 1990, Honolulu, Hawai‘i* (Berkeley: Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1990), 52, accessed December 16, 2016, [https://www.fs.fed.us/psw/publications/documents/psw\\_gtr122/psw\\_gtr122b.pdf](https://www.fs.fed.us/psw/publications/documents/psw_gtr122/psw_gtr122b.pdf).

<sup>278</sup> Merlin and VanRavenswaay, "The History of Human Impact on the Genus *Santalum* in Hawai‘i," 53.

planters became aware that protecting the forests as watersheds were vital to their industry.” Sugar became king after cattle in Hawaii and in 1876, legislation was passed to “*set apart and cause to be protected from damage by trespass of animals or otherwise, such woods and forest lands, the property of Government, as may...be best suited for the protection of water sources.*”<sup>279</sup>

In 1903, the Territorial Legislature passed Act 44, which created a division of forestry with authority to establish forest reserves. Reforestation efforts subsequently followed and in the first decade of the twentieth century wherein 800,000 acres of state and private land were set as forest reserves.<sup>280</sup> To aid the forest restoration effort, a hunting license program was created in 1907, which enlisted the help of the public to eliminate feral livestock. Tree-planting and fire control programs were also implemented. By the 1930s, more than two million trees were being planted every year.

By the 1940s, the forest reserve totaled 1.2 million acres. Eroding areas had been reforested, albeit with non-native species, and feral animals were reduced to manageable levels. The rainforest’s potential to provide water, and other goods and services such as erosion control had been recognized.<sup>281</sup>

Water also became an issue after the traditional Hawaiian model of shared resources declined. In the mid-19<sup>th</sup> century, foreigners introduced ownership which to the privatization of land and water. These properties were sold to foreign businessmen who built sugar cane plantations. Large quantities of water were needed because sugar cane is a water-hungry crop. One hundred acres of sugar cane could require as much as one million gallons of water a day.<sup>282</sup> Water needed to be diverted from the Windward to the Leeward side, leading the way to the first large-scale irrigation projects like ditches and aqueducts in Hawai‘i.<sup>283</sup>

Water diverted from the streams was not enough for the many acres of sugar cane. In 1879, water was found in Ewa by drilling. By the 1890s, artesian wells were dug everywhere, supplying most of Honolulu’s needs.<sup>284</sup> However, within 20 years, the water boom came to a

---

<sup>279</sup> Henshaw and Lewis, "The Lessons of History: Making a Case for a National Forest in Hawai‘i," 65.

<sup>280</sup> Ibid, 65-66.

<sup>281</sup> Ibid, 66.

<sup>282</sup> Richard A. Hawkins, "The Impact of Sugar Cane Cultivation on the Economy and Society of Hawai‘i, 1835-1900," *Illes I Imperis*, no. 9 (December 09, 2006): 65, accessed December 16, 2016, <http://www.raco.cat/index.php/IllesImperis/article/download/81025/105500>.

<sup>283</sup> Hawkins, "The Impact of Sugar Cane Cultivation," 66.

<sup>284</sup> Board of Water Supply, "Oahu's Water History," Board of Water Supply, accessed December 16, 2016, <http://www.boardofwatersupply.com/about-us/oahus-water-history>.

bust and at the turn of the century, O'ahu suffered a water panic.<sup>285</sup> The native Hawaiian population was powerless to stop the overburdening of their watersheds. The 1890s Territorial Government that was in place at the time placed the water system as a department under the Superintendent of Public Works of the Territory of Hawai'i. The territorial government changed the laws to accommodate profit, stating that ancient Hawaiian water and land customs were ineffective and unreliable in water distribution.<sup>286</sup> The government preferred definite terms of ownership, land rights, and resource management.

In 1896, Act 61 which provided that if the Board of Health judged any land in Honolulu unsanitary, the owner of the land was forced to improve it at his own expense. If the owner did not, the government would undertake the reclamation and the land would be sold to the highest bidder.<sup>287</sup>

Between 1913 and 1928, the Department of Public Works, the Honolulu Water Commission, and the Honolulu Sewer and Water Commission were established after each other to deal with the water crises, but none of them were successful and water shortages continued. Finally in 1929, by Act 96, the Honolulu Sewer and Water Commission was dissolved and the Board of Water Supply (BWS) was created. This Board assumed the powers of the Sewer and Water Commission as to water projects within the District, and succeeded the City and County Board of Supervisors in full management of the Honolulu Water Works. *"Its immediate objectives were to modernize the system, to meter all water distributed and to seal all faulty, leaking artesian wells to halt the waste of fresh water. In the ensuing years, these and other goals were attained."*<sup>288</sup> In 1987, the State Water Code was adopted by the Hawai'i Legislature, which set in place various layers of protection for all waters in the Hawaiian Islands. The State Commission on Water Resource Management -- also known as the Water Commission -- sets policies and approves water allocations for all water users, including the Board of Water Supply. Even though the responsibility for protecting groundwater resources was assigned to

---

<sup>285</sup> Ibid.

<sup>286</sup> *A Brief History of Water Rights in Hawai'i, with Earth Justice Attorney Isaac Moriwake*, prod. Noni Films, perf. Isaac Moriwake, Youtube, April 29, 2009, accessed December 16, 2016, <https://www.youtube.com/watch?v=6eEU2qSke7w>.

<sup>287</sup> Masakazu Ejiri, *The Development of Waikiki, 1900-1949: The Formative Period of an American Resort Paradise*, Master's thesis, University of Hawai'i, 1996 (Ann Arbor, Mich.: UMI Dissertation Services, 1998), 237.

<sup>288</sup> Board of Water Supply, "Oahu's Water History."

the Hawai'i State Department of Health, the Board of Water Supply regulates and protects watersheds and activities over the island's basal aquifers.<sup>289</sup>

---

<sup>289</sup> Board of Water Supply, "Oahu's Water History."

### 3.5 THE OLD WAIKĪKĪ

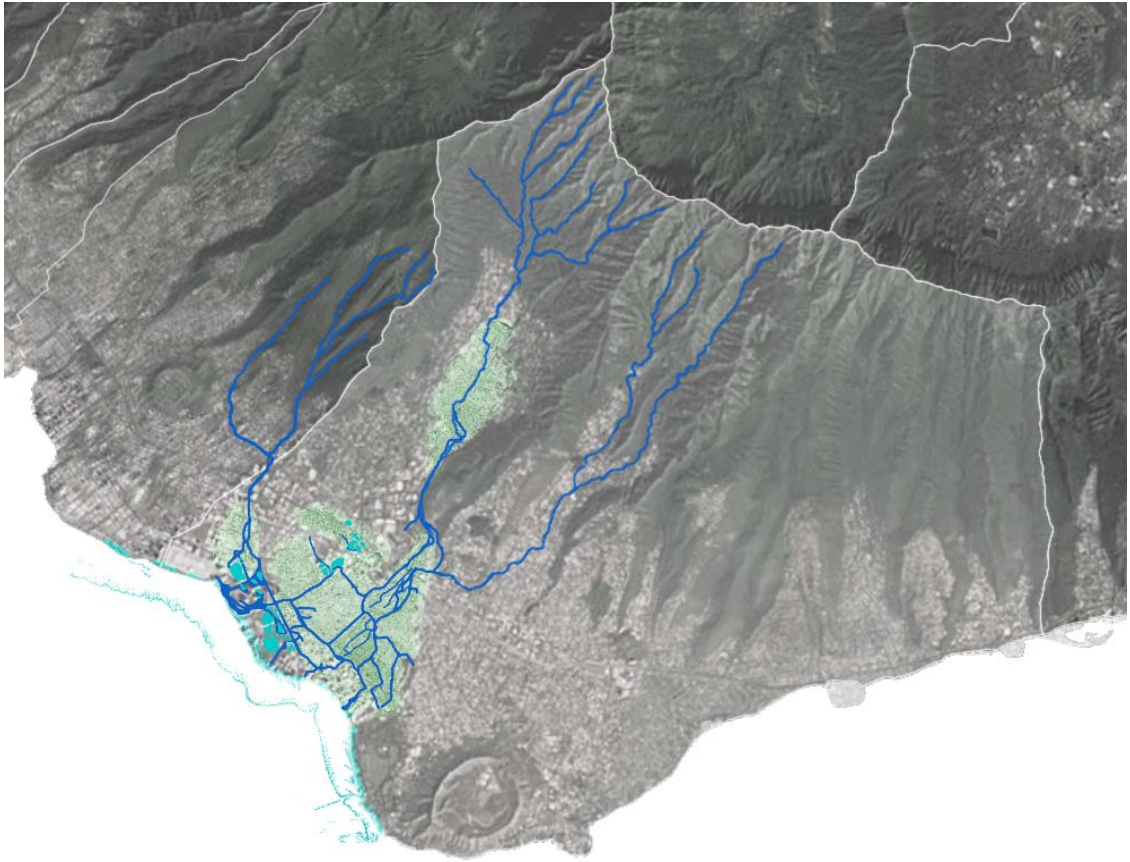


Figure 27 Ancient Waikīkī overlayed on the present day urbanized O‘ahu. Ancient waterways, known locations agricultural plots c. 1890s.

Source: By Author

#### History

Waikīkī literally means “spouting water”. The ahupua‘a of Waikīkī extended much farther from what is conceived as the boundaries of Waikīkī today.<sup>290</sup> The boundaries once encompassed 3 square miles, about 4 times the size of what Waikīkī is today. Most people know Waikīkī to be a small stretch of hotels and beach, but it was once one of the largest ahupua‘a on the island of O‘ahu.<sup>291</sup>

---

<sup>290</sup> Ejiri, *The Development of Waikiki*, 20.

<sup>291</sup> Kanahale, *Waikiki 100 BC to 1990 AD : An Untold Story*, 6.



It was called the place of “spouting waters” because it was a green watershed that was fed by streams, underground springs, the oceans, and the rains.<sup>292</sup> Waikīkī was once a sacred site for healing and sacrifice. It was favored as the dwelling and surfing spot by the ali‘i. The ahupua‘a of Waikīkī was once filled with agriculture and aquaculture, fed by the streams that flowed from three valleys—Makiki, Mānoa, and Pālolo. These streams are physical manifestations of Mauka to Makai.<sup>293</sup>

Figure 28: Taro field from McCully Street looking toward Laē‘ahi.  
Source: Ray Jerome Baker<sup>294</sup>

Waikīkī was a natural drainage landscape for the rain from the Ko‘olau mountain range in the middle of O‘ahu. Thus Waikīkī was characterized by marshes, wetlands, mudflats, duck ponds, fish ponds, and a sloping reef. George S. Kanahele, in his book “Waikīkī 100 BC to 1900 AD: An Untold Story, recreated the “unspoiled environment of old” using the “data

---

<sup>292</sup> Ejiri, *The Development of Waikiki*, 20.

<sup>293</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 4-5.

<sup>294</sup> Ray Jerome Baker, "Taro Fields," digital image, Ray Jerome Baker Collection, accessed December 10, 2016, <http://kapalama.ksbe.edu/archives/albums/old%20hawaii/album/index.html>.

preserved in chants and legends and the findings of modern science”<sup>295</sup> to describe the landscape of Waikīkī.

### Characteristics

Before westerners, because the boundaries of an ahupua‘a is largely dependent on natural features of the landscape and the resources it had, it is hard to be precise about the exact measurements of the Waikīkī ahupua‘a. Also, the watershed is ephemeral because of seasonal changes. According to Kanahele, marshland measurements are hard because their boundaries can migrate mauka or makai over time.<sup>296</sup>

The ahupua‘a of Waikīkī extended to Kou, the old name for Honolulu, to Maunalua, now referred to as Hawai‘i Kai. Today’s Waikīkī District is only a smaller portion of the ancient ahupua‘a of Waikīkī. On one side are two of the volcanic cones of the Ko‘olau rift zone, namely Laē‘ahi and Kaimukī.<sup>297</sup> There are two accepted meanings of Laē‘ahi. *Le abi* translates to “the forehead of tuna,” an observation of the volcano’s profile. The other meaning is derived from *Lei abi*, meaning “wreath of fire,” because Hawaiians would light a fire atop Laē‘ahi like a beacon to safely guide canoes to shore.<sup>298, 299</sup>

Laē‘ahi is an extinct volcano which was once said to be the home of Pele.<sup>300</sup> The bottom of its crater is about 200 feet above sea level and once contained a shallow marsh whose life depended on bursts of rain.<sup>301</sup> Today the marsh has dried up after the City and County of Honolulu installed infrastructure to drain the water that collected after heavy rains. “*The volcanic wall continues along the edges of Kapahulu where the land ascends the Kaimukī dome. Kaimukī sits on the back of an extinct shield volcano, built up after many ancient eruptions and flows of lava. Kaimukī was said to be the home of the menehune.*”<sup>302</sup> The Menehune are a mythical people who were known to completing incredible construction feats in a single night.<sup>303</sup>

---

<sup>295</sup> Kanahele, *Waikiki 100 BC to 1990 AD : An Untold Story*, 1-2.

<sup>296</sup> Ibid., 5-6.

<sup>297</sup> Ibid., 5.

<sup>298</sup> Ejiri, *The Development of Waikiki*, 24.

<sup>299</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 12-14.

<sup>300</sup> Ejiri, *The Development of Waikiki*, 24.

<sup>301</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 11-12, 16.

<sup>302</sup> Kanahele, *Waikiki 100 BC to 1990 AD : An Untold Story*, 6.

<sup>303</sup> Ibid.

Figure 29: 1929 Aerial view of the Waikīkī coast with Laē‘ahi in the background.  
Source: Paradise of the Pacific<sup>304</sup>

### **Flora and Fauna**

According to Kanahele, in Old Waikīkī, the beaches and marshlands were covered with grasses and sedges. ‘Aki‘aki and ‘akulikuli, pu‘uka‘a and ‘ahu‘awa and ‘aka‘akai grew near the shore. The ‘auku‘u (heron), koloa (Hawaiian duck), ae‘o (Hawaiian stilt), ‘alae ke‘oke‘o (coot), and ‘alae‘ula (mud hen) were birds that inhabited the marshlands. There were no warm-blooded four-footed mammals in the Waikīkī marshland. Drought resistant plants also grew in the marshland; naupaka, the koali, the pohuehue, the ‘ilima, nanea, ‘ohai, ‘iliahi, alahe‘e, the wiliwili, and the hala.<sup>305</sup>

---

<sup>304</sup> Paradise of the Pacific, "1929 Paradise of the Pacific Shows off Waikiki with Then-new Aerial Photography," digital image, Honolulu Magazine, May 25, 2013, accessed December 10, 2016, <http://www.honolulumagazine.com/Honolulu-Magazine/May-2013/From-Our-Files-Tourism/>.

<sup>305</sup> Ibid., 8-10.

## **Settlers**

The Waikīkī ahupua‘a was hypothesized to have been settled by the earlier Windward settlers who migrated to the Leeward side of O‘ahu to establish more communities. According to Kanahele, Waikīkī was the “next best place”<sup>306</sup> in their search for a similar landscape condition as their Kailua settlements<sup>307</sup>—good soil, tillable terrain, adequate rainfall, networks of streams, forested uplands, calm shores, rich marine life, and a protective outer reef.<sup>308</sup> The Waikīkī hypothesis however does not account for when the first settlement happened. Kanahele hypothesizes that Waikīkī had to have been settled before 600 A.D.<sup>309</sup>

Waikīkī’s first settlers were probably a few ‘ohana, each numbering between 20-40 people. Since each family depended on the productivity of its own collective hands for its food, clothing, and shelter, its size was critical for survival as a self-sustaining unit. The population of the ancient Waikīkī ahupua‘a remains unknown because “census information was too difficult to include in their chanted histories.”<sup>310</sup> However, it is my assumption that they would not have overburdened their ahupua‘a and instead branched out and settled another ahupua‘a.

---

<sup>306</sup> Ibid., 14.

<sup>307</sup> Ibid.

<sup>308</sup> Ibid., 12.

<sup>309</sup> Ibid., 22-23.

<sup>310</sup> Ibid., 32.

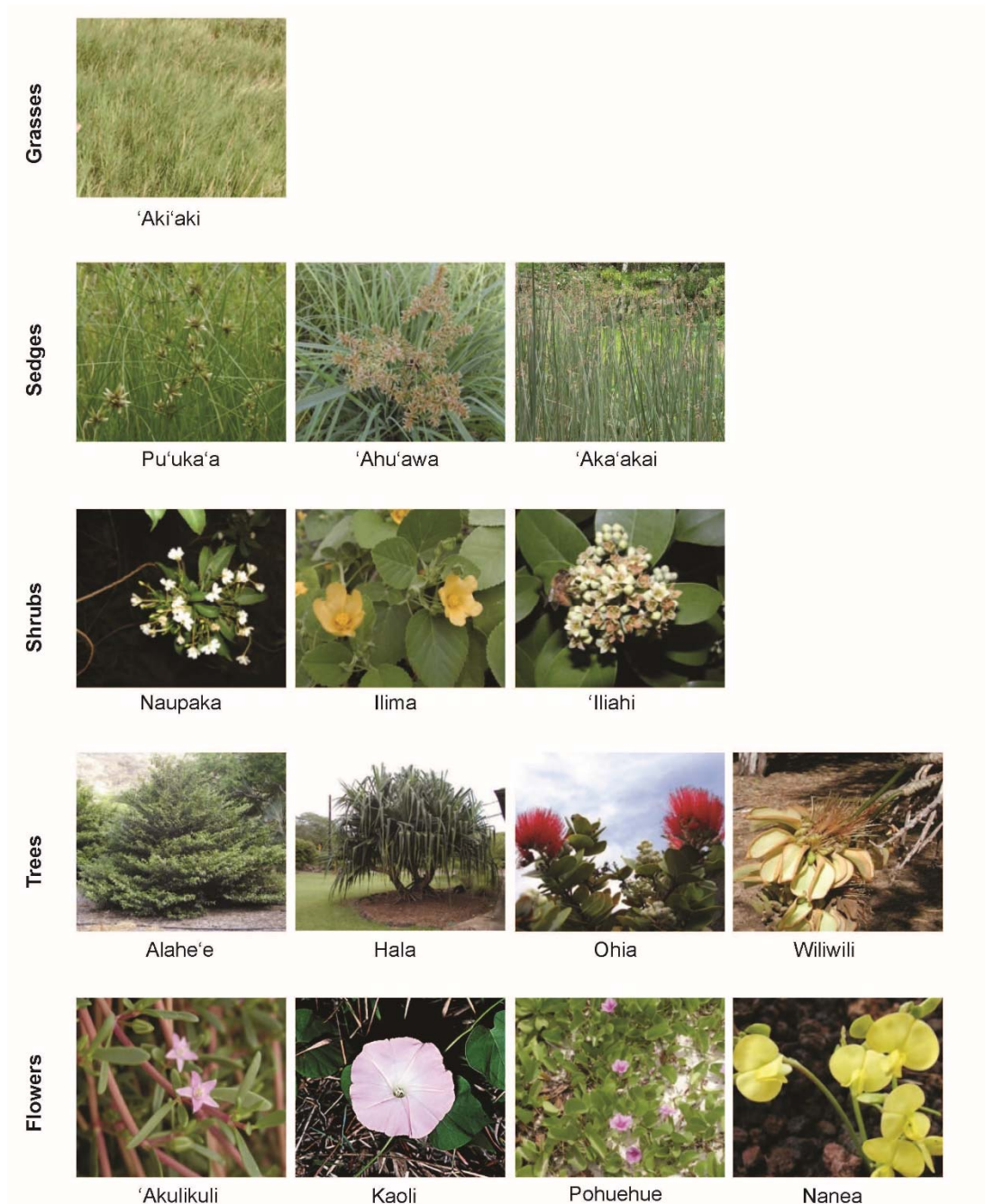


Figure 30: Ancient Waikīkī flora.  
Source: By Author

Figure 31: An 1893 map showing the expanse of agricultural food production within the coast and the midlands.  
Source: Ho'okuleana<sup>311</sup>

### **Food Production**

For spiritual and dietary needs, the settlers put priority into transforming the marshlands of Waikīkī into lo'i kalo (taro pond). According to Kanahele, *"constructing the lo'i involved having to clear the sedges, bulrushes, and other plant growth, building embankments to contain the water in the lo'i, hardening the soil by stamping on it, fertilizing it with plant material, leveling the ground and*

---

<sup>311</sup> Ho'okuleana, "Ancient Agricultural Production Intensification," digital image, Ho'okuleana, November 1, 2012, accessed December 10, 2016, <http://totakeresponsibility.blogspot.com/2012/11/ancient-agricultural-production.html>.

*constructing a simple irrigation system with ‘auwai (ditches) to bring water from the streams or springs into the lo‘i and mākāhā to regulate water flow.”*<sup>312</sup>

Waikīkī became one of the major aquaculture centers in the islands.<sup>313</sup> They created loko i‘a (fish ponds). Waikīkī’s first fish ponds were probably loko i‘a kalo, taro fish ponds, a combination of taro and fish.<sup>314</sup> “The ‘o‘opu, (goby) and āholehole (silver perch) would make their way into taro fields or canals from a stream, especially during times of rain and overflow.”<sup>315</sup> Mary Kawena Puku‘i said that lo‘i kalo were excellent subsidiary fish ponds.<sup>316</sup>

There were also inland ponds exclusively for raising fish. Most loko wai or freshwater ponds were either existing ponds or natural depressions that the Hawaiians enhanced to hold fish and connect to springs and streams. Most loko wai was located in the Kamō‘ili‘ili area. The Kumulae Spring on the site of the former Willows Restaurant on Honolulu’s Husten Street was known for its healing powers. At Kānewai, near the University of Hawai‘i’s sports complex, there was an underground pool with similar healing powers.<sup>317</sup>

Another type of pond was the loko pu‘uone –“*isolated inshore ponds formed by the development of a barrier beach that created a single, elongated pu‘uone (sand dune), parallel to the coast.*”<sup>318</sup> There were loko pu‘uone in Kālia near the Pi‘inaio Stream estuary. The fish commonly located in the inshore ponds were ‘ama‘ama (mullet) and awa (milkfish) because they thrive in the brackish waters of estuarine environments.<sup>319</sup>

### **Seat of Power**

Waikīkī became the center of the government of O‘ahu around 1450 when the chief Ma‘ilikukahi founded it as the site for the royal residence.<sup>320</sup> According to Ejiri, Kakuhikewa, one of Ma‘ilikukahi’s successors lived in Ulukou, the present site of the Moana Hotel. Ulukou and Helumoa were the primary section of Waikīkī where the Apuakehau Stream flowed

---

<sup>312</sup> Kanahale, *Waikiki 100 BC to 1990 AD : An Untold Story*, 20-21.

<sup>313</sup> Ibid., 40.

<sup>314</sup> Ibid., 41.

<sup>315</sup> Ibid.

<sup>316</sup> Ibid.

<sup>317</sup> Ibid., 43.

<sup>318</sup> Ibid.

<sup>319</sup> Ibid. 43-44.

<sup>320</sup> Ibid., 62.

through; it was a popular surfing spot.<sup>321</sup> Legend says that Kahuhiihewa planted the first coconut tree in Helumoa. Today, this site is the famous royal coconut grove in Waikīkī.<sup>322</sup> High ranking chiefs used this area for permanent residences. This site was ideal for making a royal home because of its freshwater streams, the area's elevation, and natural irrigation system, and Waikīkī's suitability as a safe harbor for war canoes. There is also the immediate availability of food and the beauty of the soft waves and surroundings.<sup>323 324</sup>

Figure 32 King Kamehameha V's residence in Helumoa.  
Source: Ho'okuleana<sup>325</sup>

Many heiau were also built in Waikīkī for kahunas or priests to conduct rituals for the chiefs.<sup>326</sup> Because of Kamehameha's encounter with Westerners, he moved his royal court to Honolulu Harbor in 1809, where he could regulate the foreign vessels that were entering the port.<sup>327</sup> This move of the "seat of power" created changes in the Waikīkī environment. By 1852, Kamehameha's royal residence had deteriorated.<sup>328</sup> Waikīkī went from a permanent royal residence to a temporary retreat<sup>329</sup>, and the taro fields that once enriched the landscape

---

<sup>321</sup> Ejiri, *The Development of Waikiki*, 75.

<sup>322</sup> Ibid.

<sup>323</sup> Ibid.

<sup>324</sup> Kanahele, *Waikiki 100 BC to 1990 AD : An Untold Story*, 92-94.

<sup>325</sup> Ho'okuleana, "Coconut Grove and Residence of King Kamehameha V," digital image, Ho'okuleana, June 26, 2012, accessed December 10, 2016, [http://totakeresponsibility.blogspot.com/2012\\_06\\_01\\_archive.html](http://totakeresponsibility.blogspot.com/2012_06_01_archive.html).

<sup>326</sup> Ejiri, *The Development of Waikiki*, 75.

<sup>327</sup> Kanahele, *Waikiki 100 BC to 1990 AD : An Untold Story*, 103-104.

<sup>328</sup> Ejiri, *The Development of Waikiki*, 78.

<sup>329</sup> Ibid.



declined.<sup>330</sup> The Great Māhele of 1848 terminated the traditional land tenure system and made land available for purchase after foreigners “pressed the king to settle land claims for both Hawaiians and foreigners.”<sup>331</sup> Foreigners wasted no time in acquiring land. In the 1850s, foreigners began settling in Waikīkī.<sup>332</sup> Ejiri described the proliferation of Western architecture in the landscape. *“From 1854 to 1874, royal beach cottages in Waikīkī were constructed of wood and grass roof. By the end of the century, there trendy white framed houses with two stories along the waterfront.”*<sup>333</sup> Following the great Māhele, the westerners who bought land in the Waikīkī area started to erect hotels.<sup>334</sup>

### **Resort for the Elites**

Waikīkī became a resort that catered to the elites. The first hotel in Waikīkī was the Park Beach Hotel. It was constructed near Kapiolani Park in 1888.<sup>335</sup> In 1901, the Moana Hotel appeared on the beach front, specifically established to *“fulfill the needs of modern, sophisticated, and affluent travelers.”*<sup>336</sup> Many other hotels were established in the first two decades of the 20<sup>th</sup> century after the Moana, accelerating the disappearance of Waikīkī’s rural character.<sup>337</sup>

Figure 33: The Moana Hotel, the First Lady of Waikīkī.  
Source: Moana Surf Rider<sup>338</sup>

---

<sup>330</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 120.

<sup>331</sup> Ibid., 114-115.

<sup>332</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 4-5.

<sup>333</sup> Ejiri, *The Development of Waikiki*, 78.

<sup>334</sup> Kanahele, *Waikiki 100 BC to 1990 AD: An Untold Story*, 152.

<sup>335</sup> Ejiri, *The Development of Waikiki*, 148.

<sup>336</sup> Ibid., 152.

<sup>337</sup> Ibid., 161.

<sup>338</sup> Moana Surfrider, "Moana Hotel," digital image, Moana Surfrider History, accessed December 10, 2016, <http://www.moana-surfrider.com/propertyoverview/hotelhistory>.

## 3.6 THE ALA WAI WATERSHED

Figure 34: Construction of the Ala Wai Canal.  
Source: Hawaii State Archives<sup>339</sup>

### **Initial Efforts in Development**

In 1896, the Legislature of the Republic of Hawaii passed Act 61. Under the Act, the Board of Health deemed any land in Honolulu as “deleterious to public health,” the owner had to improve his property or else the government would intervene.<sup>340</sup> After the overthrow and the annexation of Hawaii to the United States, Lucius E. Pinkham, the president of the Board of Health issued the “Reclamation of the Waikiki District: For the Making of Honolulu as Beautiful and Unique in Character, as Nature Has Endowed it in Scenery, Climate, and Location,”<sup>341</sup> a report in 1906 that declared Waikiki’s wetlands to be hazardous to public health and recommended that the landscape be reclaimed and suited for real estate development.

---

<sup>339</sup> Hawaii State Archives. “Moena Park and Ala Wai,” digital image, Waikiki Magazine, January 3, 2014, accessed December 10, 2016, <http://www.waikikivisitor.com/2014/ilove-waikiki/waikikis-waterway-ala-wai-canal/>.

<sup>340</sup> Ejiri, *The Development of Waikiki*, 237.

<sup>341</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 28-29.

Without any supporting data, the report claimed the Waikiki District, comprising of 687 acres of land below a 5-foot elevation<sup>342</sup> as “*being deleterious to the public health,*” “*being low, covered and partly covered with water,*” and “*being utterly incapable of surface or sewage drainage.*”<sup>343</sup> However, in his report, Pinkham was less concerned with health and was more interested in the creation of a beachfront resort community to attract wealthy guests.<sup>344</sup> Other health reports were presented following Pinkham’s such as the 1909 report, “The Outlook for the Quarantinable Diseases in the Territory of Hawaii,” by W.C. Hodby, the chief quarantine officer for the U.S. Public Health and Marine-Hospital Service. Hodby’s report advocated the extermination of mosquitoes. He produced a second report in 1912 following a case of yellow fever in 1911 that argued, “*the immense loss due to mosquitoes outweighed the value of crops that would be lost by filling wetlands*” and that “*reclamation would provide new housing tracts.*”<sup>345</sup>

### **Ala Wai Canal**

The canal was “created” to clean Waikiki’s “swamps” which were said to be health hazards. The engineering project, however, was created to drain the land of waters –to destroy the watersheds– to make the land suitable for real estate and commercial development.

Pinkham was appointed the governor of the Territory of Hawaii in 1913 by President Woodrow Wilson despite opposition by Hawaii residents.<sup>346</sup> Pinkham gained political support for the project. In 1918, a year after his term, the legislature allocated funds for the canal’s excavation.<sup>347</sup> Dillingham was a wealthy businessman and landowner who owned sizeable properties in Waikiki. He founded the Hawaiian Dredging Company in 1902, seemingly to support his plans to develop Waikiki.<sup>348</sup> He related to several political figures including Pinkham. The Hawaiian Dredging Company was contracted to create the canal and in 1921, work on the canal began.<sup>349</sup>

In Pinkham’s initial plans for the waterway, the canal was designed to have two outlets: one at Kapahulu Avenue and the other at the Ala Moana end. The canal was supposed to be

---

<sup>342</sup> Ibid.

<sup>343</sup> Ejiri, *The Development of Waikiki*, 238-239.

<sup>344</sup> Ibid.

<sup>345</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 28-29.

<sup>346</sup> Ejiri, *The Development of Waikiki*, 242-243.

<sup>347</sup> Ibid.

<sup>348</sup> Ibid.

<sup>349</sup> Andrea Feeser and Gaye Chan, *Waikiki: A History of Forgetting and Remembering*, 32.

250' wide and 20-25 feet deep, and 23,000 feet in length.<sup>350</sup> Unlike most canals, The Ala Wai is not lined with concrete floor as most canal projects are; it is carved out of pure coral, which was what the plain of Waikīkī originally was. The entire length of the canal was completed by June 1924 apart from the Kapahulu Avenue outlet because it was deemed that having an opening to the east of the planned real estate development would make the waters to the west of it dirty. Also, the project lacked funds.<sup>351</sup> The material from the Ala Wai, consisting of dredged coral bed and coralline was used to fill in the streams that emptied into the ocean. Waikīkī Drainage Canal. Because the second outlet was not built, the water at the eastern end created stagnation. The silt carried by the upland streams that once settled in the wetlands and made it lush for agriculture now caused sedimentation and uncleanness.<sup>352</sup> The Ala Wai Canal never lived up to Pinkham's ideal "Venice of the Pacific."<sup>353</sup> It had become "deleterious to public health" and is the physical antithesis to Waikiki's place name and inherent landscape characteristics.

According to Townscape Inc., who produced an analysis of the watershed in 2003, today, the length of the canal has an average width of 158 feet and it widens to 260 feet between Kalākaua Avenue and McCully Street. It tapers back to 160 feet where the Manoa Stream joins the canal. The depth of the canal varies from 10-25 feet, but due to sedimentation and lack of dredging maintenance, the depths now vary between 2-10 feet.<sup>354</sup>

The streams throughout the valleys have been seriously polluted by their adjacent urban settlements. The parts of the streams that once flowed through the sub-section now known as Waikiki Beach were completely severed from the ocean by the dredging of the Ala Wai Canal. The Ala Wai is a tear in the landscape's identity. It is a conduit for water and storm runoff and nutrients from the valleys. It has also become a sedimentation basin because of the necessary dredging to maintain its storm flow capacity. It is a source of pollution, creating adverse health effects on its users. The negative effects of the Ala Wai Watershed must be addressed not just at its present location, but throughout the entire Waikīkī matrix.

---

<sup>350</sup> Ejiri, *The Development of Waikiki*, 241.

<sup>351</sup> Ibid., 244.

<sup>352</sup> Ibid., 250.

<sup>353</sup> Ibid., 250-251.

<sup>354</sup> Townscape, Inc. and Eugene Dashiell, *Ala Wai Watershed Analysis Final Report*, report (2003), 13.

### **Kapi‘olani Park**

Kapi‘olani Park rests against Laē‘ahi, an extinct volcano. Kapi‘olani Park was conceived by King David Kalākaua who wanted to “create a park for his subjects who wanted to escape the strains of city life and get back to nature.”<sup>355</sup> The parks he had seen in American cities inspired him to build something of comparison. In June 1877, the king dedicated the site as “the first public park of the Kingdom”<sup>356</sup> and named it after his consort, Queen Kapi‘olani. However, Kapi‘olani Park did not start out as a public park. “The park was established by a private corporation whose stockholders were chiefly interested in developing an exclusive residential retreat.”<sup>357</sup>

Figure 35: Horse race track at the park.  
Source: Hawaii State Archives<sup>358</sup>

---

<sup>355</sup> Robert R. Weyeneth, *Kapiolani Park: A Victorian Landscape of Leisure* (Honolulu, HI: Dept. of Parks and Recreation, City and County of Honolulu, 1991), 3.

<sup>356</sup> *Ibid.*, 4.

<sup>357</sup> *Ibid.*, 4.

<sup>358</sup> Hawaii State Archives, "Kapi‘olani Park Racetrack," digital image, *The Honolulu Advertiser*, December 15, 2002, accessed December 10, 2016, <http://the.honoluluadvertiser.com/article/2002/Dec/15/il/il01a.html>.

The site for Kapi‘olani was sandy, arid, flat, and barren, but certain areas were prone to flooding so there were parts that were swampy. The site was used as a race course prior to the development of the park.<sup>359</sup> So in the park’s conception as a residential retreat, it was supposed to be a collection of Victorian cottages and marine villas<sup>360</sup> and the centerpiece of the housing division would be an improved race track surrounded by ornamental ponds and carriage drives.<sup>361</sup> The landscaping was to be an attractive setting for the homes of the affluent, following the lead of Olmsted: scenic urban parks that urged “contemplative recreation”<sup>362</sup> like strolling, listening to music, and boating.<sup>363</sup> The park was conceived to be 170 acres, about 1/5th the size of central park,<sup>364</sup> and integrated into the urban fabric. Approximately 100 acres were to serve as recreational areas.

Kapi‘olani Park boasts views of Laē‘ahi towering above the open spaces of the park. Laē‘ahi became the dominant feature of the park’s scenic landscape design.<sup>365</sup> Laē‘ahi is not part of the park, but its dramatic silhouette has always been integral to the distinctive “feel” of the park. The park also boasts islets, lilies, fishponds, palms, flowers, crotons and conventional “park scenery”, like flowing water and varied topography.<sup>366</sup>

The Park had a picturesque water landscape, reminiscent of its past as a thriving wetland. Through man-made infrastructure, they drained sufficient water from the portion of the park that was once where Kuekaunahi Stream flowed through to create a collection of small islands and shallow ponds.<sup>367</sup> The design of the waterscapes included wooden bridges that enabled visitors to meander among the islets. The largest piece of dry land created from the former swamp at Kuekaunahi Stream was called Makee Island, for James Makee, the president of the park’s Association. Makee Island was a favorite spot for picnics. According to Weyeneth, “although the waterways were routinely criticized as stagnant breeding grounds for moss the general picturesque effect was considered agreeable.”<sup>368</sup>

---

<sup>359</sup> Weyeneth, *Kapiolani Park*, 9.

<sup>360</sup> Ibid., 10.

<sup>361</sup> Ibid., 12.

<sup>362</sup> Ibid., 7.

<sup>363</sup> Ibid., 2.

<sup>364</sup> Ibid., 2.

<sup>365</sup> Ibid., 13.

<sup>366</sup> Ibid., 12-13.

<sup>367</sup> Ibid.

<sup>368</sup> Ibid., 12.

The waterscape of the Park was filled during the construction of the Ala Wai Canal in the early 1920s. The site of the Honolulu Zoo where the former Kapi‘olani Park waterscape features were was the proposed secondary exit of the Ala Wai Canal, but the exit was never completed.<sup>369</sup>

Figure 36: Postcard of Kapi‘olani Park with water features.  
Source: Downwind Productions<sup>370</sup>

### **Water Concerns**

The Honolulu Board of Water Supply (BWS) was created under Act 96 in 1929 by the Territorial Government “in response to public outcry for effective water management that would be free from political influence.”<sup>371</sup> The act defined the powers and duties of the BWS to include “the undertaking of investigations, surveys, and compilation of data relating to O‘ahu’s water resources and their development, utilization, and conservation.”<sup>372</sup>

---

<sup>369</sup> Ibid., 13.

<sup>370</sup> "Linen Postcard of Kapi‘olani Park C. 1920-40s," digital image, Downwind Productions, accessed December 10, 2016, [http://www.downwindproductions.com/Kapi‘olani\\_park\\_wetlands.html](http://www.downwindproductions.com/Kapi%27olani_park_wetlands.html).

<sup>371</sup> Board of Water Supply, *Water Master Plan* (Honolulu, 2016), 23, accessed December 10, 2016, <http://www.boardofwatersupply.com/bws/media/files/water-master-plan-public-draft-2016-07.pdf>.

<sup>372</sup> Ibid., 23-24.

According to the BWS Water Master Plan, the average volume of rainfall falling on O‘ahu’s watersheds is approximately 1.4 billion gallons per day, that is 0.6 billion gallons per day less than the 1922 O‘ahu Water Plan estimate which was over 2 billion gallons.<sup>373</sup> The Hawaiian Islands has seen an overall decline in rainfall of 23% in the last 30 years due to higher temperatures from climate change.<sup>374</sup> The BWS projects that Hawai‘i will experience frequent and longer droughts, heavier rains, more flash flooding, and recurring damages to BWS infrastructure.<sup>375</sup>

### **Present Day Ala Wai Watershed**

Today, the Ala Wai Watershed is located on the southeastern side of the island of O‘ahu. The watershed is 12,000 acres or 19 square miles and includes the areas between Punchbowl Crater and Laē‘ahi.<sup>376</sup> Three sub-watersheds—Makiki, Mānoa, and Pālolo drain through the watershed. The study area is the most densely populated watershed in Hawai‘i with approximately 200,000 residents.<sup>377</sup> Within the urban footprint, the population density is one of the highest in the nation with 12.36 persons per urbanized acre. Waikīkī District, within the watershed, is the primary economic engine for the State, providing 7 percent of the gross state product, 7 percent of the civilian jobs in the state, and 9 percent of the state and county tax revenue. Waikīkī has over 79,000 visitors a day.<sup>378</sup>

The watershed includes upper, middle, and lower sub-watersheds. According to the USACE report, *“the upper watershed, approximately 7.5 square miles, is zoned as Conservation District to protect the island’s aquifer. The middle and lower part of the watershed is urbanized, supporting 1,600 businesses, 21 public schools, 17 private schools and two universities, including the University of Hawai‘i at Mānoa, the largest university in the state.”*<sup>379</sup> There are more than 50 parks and parklets in the Ala Wai Watershed. The parks provide water-based activities, nature-based activities, sports activities, and interpretive activities.

---

<sup>373</sup> Ibid., 88.

<sup>374</sup> Ibid., 97.

<sup>375</sup> Ibid.

<sup>376</sup> Townscape, Inc. and Eugene Dashiell, *Ala Wai Watershed Analysis Final Report*, report (2003), 16.

<sup>377</sup> AlaWaiChallenge.org, Area Information.

<sup>378</sup> Army Corps of Engineers, *Ala Wai Canal Project, Oahu, Hawaii Feasibility Study with Integrated Environmental Impact Statement*, by United States Army Corps of Engineers (USACE) (2015), 5.

<sup>379</sup> Ibid., 5-6.



Within the study area, it often rains in the uplands and rarely near the coast. The peak flow rate from mountains to sea is approximately 30 minutes. Storms are very sudden and stormwater runs across the landscape very quickly. According to the USACE, the flashiness of Hawaii's streams causes concern because *“the suddenness of the flood events and the associated high velocities, floods within the watershed threaten human life and may result in significant urban damages. Rarely does the watershed experience long periods of standing water from a flood event. However, when heavy rains do occur over multiple days, standing flood waters become a problem.”*<sup>380</sup>

Based on U.S. Army Corps of Engineers (USACE) hydrology and hydraulic modeling, the majority of the peak flow is from the Mānoa Stream, with Pālolo Stream being the second highest contributor and Makiki Stream the third. The focus of the design will focus on the Mānoa Stream. The proposals and alternatives for the Ala Wai Watershed's infrastructure are simply different methods of hydromodification and do not address the landscape and its sense of place. Ideally, the urban infrastructure of the future Ala Wai watershed should be integrated with the natural landscape to perform as hybrid infrastructure.

---

<sup>380</sup> Ibid., 6.

## **IV PRECEDENTS**

## 4.1 SIMILAR INDIGENOUS WATERSHED MODELS

### Subak: Water Temples and Water Management

Figure 37: Subak irrigation by Balinese farming communities.  
Source: University of Arizona<sup>381</sup>

According to UNESCO, the subak reflects the philosophical concept of Tri Hita Karana, which brings together the realms of the spirit, the human world and nature. This philosophy was born of the cultural exchange between Bali and India over the past 2,000 years and has shaped the landscape of Bali.<sup>382</sup> Subak is the water management model employed in Bali, Indonesia for paddy field. The subak was developed in the 9<sup>th</sup> century. The system is irrigation organized by a “network of water temples” that is separate from the state, making the subak a localized system of water management. According to Stephen Lansing, “a rice

---

<sup>381</sup> University of Arizona, "Irrigation Water Is Shared by Balinese Farming Communities in Ways That Benefit the Community at Large.," digital image, UANews, February 5, 2013, accessed December 10, 2016, <https://uanews.arizona.edu/story/ua-anthropologist-authors-world-heritage-site-in-bali>.

<sup>382</sup> UNESCO World Heritage Centre, "Cultural Landscape of Bali Province: The Subak System as a Manifestation of the Tri Hita Karana Philosophy," UNESCO World Heritage Centre, section goes here, accessed April 06, 2017, <http://whc.unesco.org/en/list/1194>.

terrace is a complex artificial ecosystem. The water temples make decisions which manipulate the states of the system, at ascending levels in regional hierarchies.”<sup>383</sup> For example, when the regional water temple institutes a fallow period to control a pest outbreak, it is managing the regional terrace ecosystem in the landscape, not just the immediate irrigation of water.

According to Lansing, the temples themselves play no direct role in agricultural management. “But by marking the downstream terminus of a water temple network, they play an important part in the internal logic of the water temple system.”<sup>384</sup> The ability of water temple networks to function as ecosystem regulators is predicated on fulfilling a role in Balinese cosmology which links the instrumental logic of agricultural decisions in a wider religious context, much like the parallels between the ahupua‘a water management model and the Hawaiian kapu.

The separation of the water temple system from politics helped to preserve it, unlike the ahupua‘a model. However, the invisibility of such an important landscape infrastructure system ended up working to its disadvantage, in light of modernization. According to Lansing, foreign consultants encouraged changes in irrigation management. The Balinese were encouraged to use new high-yielding rice varieties, new fertilizers, pesticides, and new cropping patterns. The farmers were instructed to ignore the temple-scheduling system and continue to plant, ignoring fallows to increase yield production.<sup>385</sup>

While cosmological ceremonies continued in the water temples, the water management system did not reflect these. Because of ignoring the subak, which was related to cosmology and natural processes, pests, bacteria, and diseases within the rice ecosystem increased rapidly. And while imported pesticides did help with the pest population, the pesticides also killed eels, fish and other organisms that the farmers grew along with rice. To the foreign consultants, the part that water temple systems played in the effective water management of entire landscapes were invisible.<sup>386</sup>

---

<sup>383</sup> J. Stephen Lansing, "Balinese "Water Temples" and the Management of Irrigation," 89, no. 2 (1987): 338, accessed April 6, 2017, <http://www.jstor.org/stable/677758>.

<sup>384</sup> Ibid.

<sup>385</sup> Lansing, Balinese "Water Temples", 339.

<sup>386</sup> Ibid.

## Cordillera Terraces: Water Management & Communal Responsibility

Figure 38: Cordillera rice terraces.  
Source: Patrick Venenos<sup>387</sup>

According to UNESCO, the Rice Terraces of the Philippine Cordilleras are an outstanding example of an evolved, living cultural landscape that can be traced as far back as two millennia ago in pre-colonial Philippines. The terraces are in the remote areas of the Philippine Cordillera mountain range on the northern island of Luzon, Philippine archipelago. While the historic terraces cover an extensive area, the inscribed property consists of five clusters of the most intact and impressive terraces, located in four municipalities.<sup>388</sup> They are all the product of the Ifugao ethnic group, a minority community that has occupied the mountains for thousands of years. The Ifugao peoples' rice-terraced fields in the Cordillera Mountains of the Philippines represent portions of an agricultural system that consists of

---

<sup>387</sup> Patrick Venenos, Rice terraces of the Philippine Cordilleras, digital image, UNESCO, accessed December 10, 2016, [whc.unesco.org/en/documents/129330](http://whc.unesco.org/en/documents/129330).

<sup>388</sup> UNESCO World Heritage Centre, "Rice Terraces of the Philippine Cordilleras," UNESCO World Heritage Centre, section goes here, accessed April 06, 2017, <http://whc.unesco.org/en/list/722>.

intensive and extensive components linking indigenous knowledge of the natural environment, technological knowledge, and social organization. The distribution of rice terraces occurs over a wide range of geographic regions and climates, just like the ahupua'a's applicability to the different climatic regimes that occur on the Hawaiian Islands. Similar to the Hawaiian societal structure, the Ifugao had a ranked social system that was required for maintaining their agricultural systems of terraced pond-fields, swidden fields, rice terraces and management of forests that relied on water sharing.

Indigenous water management models develop from landscape identity—the relationship between the physical and cultural environments. This relationship resulted in a cooperative social organization if it is to prosper. The communities around the Cordillera Mountains shared water because of laws, just like the *kapu*. According to Acabado, “as in religious systems, the more flexible and encompassing the rules of access and usage are, the more lasting and resilient the water management system.”<sup>389</sup> Rice production and the construction and management of terraces is a communal responsibility.

---

<sup>389</sup> Acabado, Stephen B. "The archaeology of the Ifugao agricultural terraces: antiquity and social organization." PhD diss., University of Hawaii, 2010, 23.

## 4.2 LOCAL PLANS OF ACTION

### Mānoa Stream Park Conceptual Plan

The Mānoa Stream Park Conceptual Plan was submitted to the University of Hawaii at Mānoa in 1976. The masterplan features a wide green corridor consisting of parks from *mauka* to *makai* that will serve as major recreational areas for communities that the Mānoa Stream passes through such as Mānoa, McCully, Moiliili and Waikīkī. It also features a continuous trail system from Mānoa Falls to the ocean at Waikīkī. The master plan uses the stream as the design driver as it is meant to “enhance and expand the stream’s natural features and characteristics and propose the stream as the primary circulation spine.”<sup>390</sup>

The primary users for the stream park were the adjoining citizens from the communities that the Mānoa Stream passes through, students from adjoining primary, secondary, and collegiate schools, tourists, and island residents. Users from abutting communities will have opportunities for fishing, picnicking, strolling, and hiking. The educational community will be able to utilize the stream as an educational resource and students within the ahupua‘a will be able to cycle or walk to school through the stream park trail. Tourists will be able to enjoy an eco-touristic experience by visiting different destinations throughout the stream park from Waikīkī to Mānoa Falls. The general resident population of O‘ahu will be able to use the parks system as well for recreational activities such as boating, hiking, fishing, canoeing, and exercising.<sup>391</sup>

The conceptual plan had a framework of four elements. Streamways included design guidelines for trails and bikeways, types of edge conditions, variety of textures and materials to enhance stream characteristics, and plans to beautify areas immediately adjacent to the stream. Access includes guidelines for points of access to the streamway through bisecting streets and addresses opportunities to connect the streamway to public transportation hubs, public amenities, schools, and commercial areas. Secondary elements recommended expanding the range of the stream park throughout the urban areas by connecting existing public amenities, parks, and nodes of interest that are not adjacent to the stream through

---

<sup>390</sup> Mānoa Stream Park Conceptual Plan, 1976, Mānoa Stream Park Conceptual Plan, Honolulu, in Manoa Stream Park Conceptual Plan, by Advisory Committee for Manoa Stream Park (Honolulu, 1976), 7.

<sup>391</sup> Ibid.

pathways. Abutting land uses were policies to guide future development or redevelopment of commercial and residential adjacent properties.

Figure 39: Plan of the Mānoa Stream Park  
Source: Mānoa Stream Park Conceptual Plan<sup>392</sup>

---

<sup>392</sup> Mānoa Stream Park Conceptual Plan, 1976, Mānoa Stream Park Conceptual Plan, Honolulu, in Manoa Stream Park Conceptual Plan, by Advisory Committee for Manoa Stream Park (Honolulu, 1976).



## **Restoring Hawaiianness to Waikīkī**

In 1994, George S. Kanahele prepared a report for the Queen Emma Foundation called “Restoring Hawaiianness to Waikīkī.” The report contained a comprehensive set of recommendations and ideas that would bring clarity through Waikīkī’s rich, 2000-year-old history in the muddled “plasticity” of the current Waikīkī. The report is broken down into fifteen specific topics such as “Water-forms and Land-forms,” and “Native Plants.” Each topic states a goal, a rationale, and a numbered list of specific ideas to achieve the goal. The most pertinent topics to this design dissertation include: Water-forms and Land-forms, Native Plants, Myths and Legends, Aloha Proxemics, and Waikīkī Historic Trail.

Water-forms and Land-forms discussed the restoration, creation, and maintenance of water-dominant facilities and activities to reestablish an ecological continuity between ancient and modern Waikīkī.<sup>393</sup> Specific ideas of interest include recreating the water gardens in Kapi‘olani Park prior to the Ala Wai Canal Project, creating “natural” springs to demonstrate the meaning of Waikīkī, and clean the Ala Wai Canal.<sup>394</sup>

Native Plants discussed the preservation and maintenance of Hawaiian flora. Specific ideas for nurturing a native plant palette in Waikīkī included creating native plant gardens, planting native shade trees instead of the non-native banyan, and bringing user attention to what the native plants are by signage.<sup>395</sup>

Myths and Legends discussed the use of myths and legends in understanding and appreciating the culture, and enhancing the sacredness of Waikīkī. Specific ideas of interest include incorporating mythic themes in design and graphics, and encouraging walking tours.<sup>396</sup> Aloha Proxemics recommended maximizing opportunities for people to socialize by providing sidewalk seating, creating nodes of gathering like street art installations, connect these nodes via a trail, and maximize pedestrian foot paths to discourage driving.<sup>397</sup> Waikīkī Historic Trail discussed establishing an educational route designated by physical signage that tell the story of ancient and modern Waikīkī.<sup>398</sup>

---

<sup>393</sup> Ibid., 4.

<sup>394</sup> Ibid., 5.

<sup>395</sup> Ibid., 23-26.

<sup>396</sup> Ibid., 43.

<sup>397</sup> Ibid., 52.

<sup>398</sup> Ibid., 54-56.

While the report is meant for the modern-day Waikīkī, meaning only areas *makai* of the Ala Wai Canal, there are many specific ideas that Kanahele recommended that could enhance not just the Waikīkī entertainment district, but the entire ahupua‘a.

### **Ala Wai Canal Flushing System & Ala Wai Golf Course Detention System**

Figure 40: Conceptual plan for the Ala Wai Golf Course Detention System.  
Source: Mitsunaga & Associates, Inc.<sup>399</sup>

In 2015, the Department of Land and Natural Resources (DLNR) proposed to improve the water quality of the Ala Wai Canal by decreasing sources of pollution through the use of detention ponds and filters on tributaries to the canal. The report discussed diverting storm water into the Ala Wai Golf Course and investigated flushing systems to lessen sedimentation in the canal and to clean the water.

The existing Mānoa-Pālolo Stream drains a lot of sediment and storm water into the Ala Wai Canal. To improve the water quality, the report recommends allowing the storm water to enter the golf course and flow through a series of ponds before emptying into the Ala Wai Canal. In addition, berms parallel to the canal will be installed along the length of the golf course in order to increase storm water storage within.

---

<sup>399</sup> *Conceptual Plan*, February 2015, Honolulu, in *Ala Wai Canal Flushing System and Ala Wai Golf Course Detention System*, by Mitsunaga & Associates, Inc. (Honolulu: DLNR, 2015).

The proposed ponds include a sedimentation basin, an irrigation pond to provide additional volume and irrigation water for the golf course, and lastly, a water quality filtration marsh pond to help filter pollutants and allow even more sediment from the water to settle before letting it out through a broad crested weir directly into the Ala Wai Canal. The sediment basin is proposed to be 8 feet in depth, the irrigation pond will be 6 feet in depth, with a pump and pipe to and from to irrigate the golf course. The water quality filtration marsh pond will vary in depth.

To divert water from the Mānoa-Pālolo Stream, the report proposes a rubber dam 1500 feet above the confluence of the Stream and the Ala Wai Canal. An inlet will be located before the dam which will lead into the sedimentation basin and the rest of the pond filtration system.

### **U.S. Army Corps of Engineers NED Plan**

In 2015, the United States Army Corps of Engineers recommended a plan of action to mitigate the flood risk vulnerability of the Ala Wai Watershed. The tentatively selected plan is the National Economic Development (NED) plan and consists of the following projects: (1) six in-stream debris and detention basins in the upper reaches of the watershed, (2) one standalone debris catchment feature (3) three multi-purpose detention basins in open space areas through the developed watershed, (4) 1.7 miles on the left bank and 0.9 miles on the right bank of floodwalls along the Ala Wai Canal, including 3 associated pump stations, (5) non-structural improvements to the flood warning system, and (6) mitigation features based on criteria of the Federal and State Dam Safety Programs.<sup>400</sup>

The USACE also outline key environmental impacts include those related to biological processes, aquatic habitat, cultural resources, and visual resources. In general, the flood risk management measures would introduce a large-scale built element to the natural environment, potentially affecting view from and toward the site. The detention features would be screened by dense vegetation or otherwise designed to fit into the natural topography, such that they are not expected to be prominently visible from any readily accessible public locations.<sup>401</sup> The proposed measures along the Ala Wai Canal, including the floodwalls, would diminish mauka

---

<sup>400</sup> Army Corps of Engineers, *Ala Wai Canal Project, Oahu, Hawaii Feasibility Study with Integrated Environmental Impact Statement*, by United States Army Corps of Engineers (USACE) (2015), 164-168.

<sup>401</sup> Ibid., 1041.

to makai views in the watershed. Despite the visual impact of the engineering infrastructures, the USACE feasibility analysis determined that they would be a necessary feature to provide adequate flood protection for the Ala Wai Canal area, and as such, some degree of impact is unavoidable.<sup>402</sup>

---

<sup>402</sup> Ibid.

Figure 41: USACE plan for the Ala Wai Watershed.  
Source: USACE<sup>403</sup>

## 4.3 PU‘UHONUA – PLACES OF REFUGE

### ‘Aihualama Stream Loi

‘Aihualama Stream runs through the Lyon Arboretum in the upper reaches of Mānoa Valley. It is one of the tributaries that contribute to the Mānoa Stream. There are two lo‘i located on the east and west of the stream. The 1-acre system of lo‘i at the site were given the name ‘Aihualama after the ili it is located in and from the stream that sustains it.<sup>404</sup> The west side’s lo‘i was constructed in the 1970s and has been used to grow kalo and other food plants. The east side’s lo‘i was once an ancient lo‘i, evident of its prehistoric walls and ‘auwai. Because ‘Aihualama has an abundance of natural springs and rain because it is in the upper portion of the ahupua‘a. The ‘auwai system diverted very little from the adjacent Aihualama Stream. Instead, the auwai functioned to slowly collect spring water and surface water, clean it through the lo‘i, and then return it back to the stream.<sup>405</sup>

“Through the efforts of community experts, Hālau Kū Māna charter school teachers and students, and Lyon Arboretum, lo‘i that had been dormant for over 100 years are now living again..”<sup>406</sup> The lo‘i were restored for cultural preservation and to be used as an educational resource. The Aihualama Lo‘i is considered a sanctuary for students and community members to cultivate a relationship with the land, to engage in subsistence and collective work, and to practice a mode of education geared towards naturalistic systems.<sup>407</sup>

Since 2006, students working in the lo‘i opened approximately one new field per year, and learned and practiced all phases of cultivation: from putting huli in the ground to making ‘ai (food). There are now over 30 varieties of kalo in the ‘Aihualama collection, there are plantings of ‘uala (sweet potato), niu (coconut), ti, ‘olena (turmeric), ‘awa (kava), hō‘i‘o (a native fern) and kö (sugar cane).

### Ka Papa Lo‘i ‘O Kānewai

---

<sup>403</sup> Army Corps of Engineers, *Ala Wai Canal Project, Oahu, Hawaii Feasibility Study with Integrated Environmental Impact Statement*, by United States Army Corps of Engineers (USACE) (2015).

<sup>404</sup> Hulili, 171.

<sup>405</sup> Alternative, 62.

<sup>406</sup> Hulili, 171.

<sup>407</sup> Lyon Arboretum Final Environmental Assessment, 50-52.

Figure 42: Kāne and Kanaloa

Source: HSHK<sup>408</sup>

According to the story associated with the area known as Kānewai, the gods Kāne and Kanaloa were swimming in the Kahala area. After their swim, they wanted to rinse off and drink water. The two searched for water and headed to the Mō'ili'ili area. Kanaloa became frustrated and began to tease Kāne and his abilities to find fresh water because they searched for a long time and found no water. Kāne finally located a spot where he thought there was fresh water. Kāne struck the ground with his o'o and a huge spring of cool fresh water sprung up. The two gods were able to rinse the sand off their bodies, drink water and 'awa. The area where Kāne created the spring is called Kānewai, the area that the sand washed off their bodies is called Kanaloa.

Ka Papa Lo'i 'O Kānewai is a cultural garden located in the University of Hawai'i at Mānoa's Hawai'inuiākea School of Hawaiian Knowledge. It is adjacent to the Mānoa Stream. The pu'uhonua is located in Waikikī, so it is a perfect example of ahupua'a concepts being

---

<sup>408</sup> HSHK, "Kane and Kaneloa," digital image, Hawai'inuiākea School of Hawaiian Knowledge, accessed December 10, 2016, [http://manoa.hawaii.edu/hshk/ka-papa-loi-o-kanewai/history/kane\\_kanaloa/](http://manoa.hawaii.edu/hshk/ka-papa-loi-o-kanewai/history/kane_kanaloa/).

implemented within the study area of this design research. The garden features an 800-year old lo'i that has been used by many generations since. Kānewai features a collection of kalo and a variety of native trees, shrubs, and groundcover along the borders of the loi and along the slopes of the stream. Families, students, and community organizations can immerse themselves in hana Hawai'i and 'ōlelo Hawai'i (Hawaiian activity and language). Kūpuna feel welcome and comfortable sharing their knowledge about kalo and nā mea Hawai'i (all things Hawaiian). Our staff is skilled in the identification, cultivation, and propagation of a variety of native plants. Students of Manoa rediscovered the abandoned 'auwai in 1980 and began growing kalo and other native plants. Since then, the traditional water diversion systems of the lo'i were restored. Kānewai is considered to be a pu'uhonua, a refuge, for people, plants, and animals.

Figure 43: Layout of loi in Kānewai  
Source: Ka Papa Lo'i 'o Kānewai <sup>409</sup>

---

<sup>409</sup> Ka Papa Lo'i 'o Kānewai, "Kānewaie," digital image, Welina Manoa, accessed December 10, 2016, <https://welinamanoa.org/for-educators/classroom-0-8/>.





Figure 44: Mānowai  
Source: By Author



Figure 45: Po'owai  
Source: By Author



Figure 46: 'Auwai  
Source: By Author



Figure 47: Makawai  
Source: By Author

## 4.4 LANDSCAPE INFRASTRUCTURE

In addressing the problems of hydromodification in the Ala Wai Watershed, the focus of applied infrastructure should be to mimic nature to filter, soak up, and store water on site and minimize the amount of surface water being taken off-site. The two parts of the ahupua‘a’s ecological zones that played roles in filtering, sponging, and holding water were the wao akua upland rainforest and the kaha kai coastal wetlands, however the urban fabric can also play a vital role in addressing the problems of hydromodification. Natural infrastructure in the form of (1) re-vegetating patches adjacent to the streams to extend the upland rainforests within the urban landscape, (2) re-constructing wetlands on transitionary edges can perform to minimize the amount of surface water that flows through the landscape and clean the water from urban areas before they enter receiving waters, and (3) embedding natural infrastructure within the urban setting to educate, inform, and reveal the inherent characteristics of the past, and the present landscape, and the evolution of the future landscape will be studied as precedents for the design solution of the Ala Wai Watershed context.

### **Reforestation**

#### *The Yarra Yarra Biodiversity Corridor by Carbon Neutral*

The Yarra Yarra Biodiversity Corridor is a multi-species native reforestation project located in Southwest Australia, a global biodiversity hotspot just like Hawai‘i. Carbon Neutral has a vision to reconnect these valuable remnant vegetation sites and link 12 patches of nature reserves across a vast tract of land covering approximately 3860 square miles. The project was established on degraded, semi-arid agricultural land that no longer supported viable farming practices with the goal of returning the environment to its origins.

Up to 40 native tree and shrub species indigenous to the region were planted. Seeds and seedlings are planted alongside fragmented remnant vegetation and nature reserves, with the design objective of restoring the project landscape to its natural condition of vegetation. This project aims to recreate a healthy and functioning landscape, restored after decades of habitat loss and degradation.

Figure 48: Diagram of linking patches of nature reserves across a landscape.  
Source: Carbon Neutral<sup>410</sup>

*Sims Bayou by the USACE*

Houston residents have always coped with flooding. The humid subtropical climate produces an average of 46 inches of rain per year, and the region's relatively flat terrain, with moderately impermeable to highly impermeable soils, creates wide, natural floodplains for water to slowly infiltrate or move. Flooding of property is a constant problem. The Sims Bayou Federal Flood Damage Reduction Project can provide protection from a 25-year flood, which statistically has a 4% chance of occurring each year and removed the 1% flood risk from 35,000 homes and 2,000 business.

USACE proposes using the full width of the right-of-way flood plain to make the channel even wider than the original 300 feet, thereby slowing down the flow of water and protecting against erosion. In place of the typical trapezoidal cross section for channels, the proposal mimics nature with a small bottom stream to handle annual flows and a series of gradually sloping embankments and flood benches to handle

---

<sup>410</sup> Carbon Neutral, "Yarra Yarra Biodiversity Corridor," digital image, Carbon Neutral, accessed December 10, 2016, <https://carbonneutral.com.au/>.

greater flows. Rather than lining the channel with solid concrete, open-celled concrete mats are placed along the channel bottom and lower slopes, which allows vegetation to grow, provides habitat for fish, and helps to mitigate erosion.

Figure 49: Aerial view of gradually sloping embankments.  
Source: SWA<sup>411</sup>

More than 18,000 trees are planted along the slopes and top of bank of the bayou. They planted several hardwood forests trees, along with woody shrubs and smaller trees serving as understory. These plants provide tree canopy for portions of the bayou's conservation area. Forty-nine trees per acre were planted above the top bank. Fourteen trees per acre, along with native grasses, were planted in the slopes of the flood benches to encourage diverse habitat, reduce erosion, and to add to the visual presence of the bayou.

The neighborhoods adjacent to and affected by the flood plain were asked to see the bayou as a river constantly moving and reshaping itself and to recognize that the coastal tree species growing along its banks were short-lived and, over time, would continually regenerate. After many severe rainstorms, there has been no flooding along

---

<sup>411</sup> SWA, "Sims Bayou Aerial Shot," digital image, SWA, accessed December 10, 2016, <http://www.swagroup.com/projects/sims-bayou/>.

the newly configured bayou. The success of Sims Bayou has led both professionals and residents to seek more innovative solutions to flood management.

### **Constructed Wetlands**

*Sidwell Friends School, Washington, D.C.*

Figure 50: Sidwell Friends Constructed Wetland Plan  
Source: Andropogon Associates, Ltd.<sup>412</sup>

---

<sup>412</sup> Andropogon Associates, Ltd., "Sidwell Friends Middle School Plan," digital image, Landscape Performance, accessed December 10, 2016, <https://landscapeperformance.org/case-study-briefs/sidwell-friends-middle-school>.

At the Sidwell Friends School, the middle school building surrounds a central courtyard that features a terraced wetland, rain garden, and habitat pond. The courtyard captures, filters, and re-uses building wastewater and site runoff. Middle school students learn about ecological systems, witness environmentally responsible systems, wherein it has become integrated in the school's curriculum. Students become aware of the valuable role that wetlands play in purifying water. The design features a wastewater treatment system that utilizes a designed landscape to filter more than 3,000 gallons of sewage and wastewater each day. The process begins by collecting wastewater into settling tanks to remove suspended solids. The water is then transported to the upper terraces of the constructed wetlands where the dirty water trickles slowly downhill through the sand and gravel of each terrace to be filtered and cleaned. Native plant species were chosen for their ability to take up toxins and heavy metals and to increase bio-diversity in the area. The water circulates through the constructed wetland for three to five days before being re-used.

Figure 51: Section of the constructed wetland.  
Source: Andropogon Associates, Ltd.<sup>413</sup>

In addition to a sophisticated wetland system, all hard surfaces, including plazas and paths, are surrounded by vegetated swales, which allow rain water infiltration. The school also boasts a green roof on top of the new middle school building. The green roof absorbs the water to sustain a native plant community. Clean overflow water from rain is directed to storage tanks and used to refill the habitat pond during dry weather.

---

<sup>413</sup> Andropogon Associates, Ltd., "Entering the sunken courtyard in front of the Middle School building, visitors step down to the constructed wetlands, rain garden and biology pond," digital image, Landscape Performance, accessed December 10, 2016, <https://landscapeperformance.org/case-study-briefs/sidwell-friends-middle-school>.

*Tianjin Qiaoyuan Park: The Adaptation Palettes*

Tianjin Qiaoyuan Park was inspired vegetation communities within the landscape that adapt to changes frequent or gradual changes. The design intent was to create a framework wherein the dynamic processes of adaptation and succession would naturally occur. The design refrains from restoring the site to some historic natural state. Rather, the rationale was that natural functions were bound to be reestablished. Twenty-one pond cavities of varying sizes and depths were carved out. Some below ground level and some above on mounds. The resulting park is a mix of water ponds, wetlands, seasonal pools, and dry cavities. The quality of soils in the cavities is in constant flux. Dryer cavities improve through the wash and filtration effects of seasonal rains, while deeper ponds capture stormwater runoff and nutrients. The resulting landscape was comprised of rich patches of seasonal vegetation that responded to subtle changes in the environment. Visitors experience the site following red-colored asphalt paths that weave through the palettes with interpretive signs and wood platforms that extend into the ponds and cavities.

Figure 52: Palettes  
Source: Turenscape<sup>414</sup>

---

<sup>414</sup> Turenscape, "Site Plan," digital image, American Society of Landscape Architects, accessed December 10, 2016, <https://www.asla.org/2010awards/033.html>.



Figure 53: Cells consisting of seasonal vegetation.  
Source: Turenscape<sup>415</sup>

### **Natural Infrastructure in the Urban Setting**

#### **Lewis Avenue Corridor**

Las Vegas is an amalgam of extreme experiences symbolizing the past, the present, and the future through its constantly evolving urban fabric. In the early 1800s, areas of the Las Vegas Valley contained artesian wells and supported meadows. Over time, the city became known as the entertainment capital of the world. Las Vegas is a “no-place entertainment capital”, much like Waikīkī District. Meanings and symbols of landscape are lost. However, there is a collective memory within residential communities, parks, and the downtown areas.

---

<sup>415</sup> Turenscape, "Site Plan," digital image, American Society of Landscape Architects, accessed December 10, 2016, <https://www.asla.org/2010awards/033.html>.

Figure 54: Photos  
Source: SWA<sup>416</sup>

SWA, the design team, transformed a former single-use parking lot and alley into a linear urban park. The design connects the Regional Justice Center and a U.S. Federal Courthouse. The linear park is a connective natural infrastructure. It provides a continuous canopy of shade for three city blocks while helping unify and revive the office and residential core in its surroundings by acting as a social hub. Lewis Street Corridor has become a catalyst for private office, retail, and residential development, much like the New York High Line.

Lewis Street Corridor symbolizes a process of reclaiming the loss in landscape identity. The design logic is derived from the area's dynamic topography, creating a diversity of desert environments. Wooded canyons, seasonal washes, exposed rock faces, eroded edges, rocks, cracked earth, waterfalls, and native vegetation describe the natural patterns and elements that deserts create in the landscape after years of seasonal rainfall and wind.

The corridor is a quarter of a mile long, running along four city blocks of Lewis Avenue. The spatial layout of the corridor is comprised of four main areas: a multifunctional plaza and arroyo, a tree-lined pedestrian walkway, the "Poet's Bridge" and a waterfall surrounded by native vegetation and stone.

---

<sup>416</sup> SWA, "Lewis Avenue Corridor," digital image, SWA, accessed December 10, 2016, <http://www.swagroup.com/projects/lewis-avenue/>.

Lewis Avenue was broken into a series of programmatic elements, namely water (memory), people (activities), and rocks and vegetation (physical character). The water elements reference to the past seasonal washes of the regional desert landscape, the recreation in the corridor's spatial layout is the social element, and finally, the choice of rocks and vegetation transform the site to reflect desert character and canopy.

### *Cheonggyecheon Stream Restoration Project*

The Cheonggyecheon Stream Restoration Project is a 3-and-a-half-mile green corridor running east to west for pedestrians, bicyclists, plants, and animals. The restoration reestablishes connections between bodies of water. The Cheonggyecheon joins the Jungraechon Stream, which leads out to the Han River. Wetlands were formed at the junction of the Cheonggyecheon and the Jungraechon. The wetlands provide ecosystem services, serving as spawning grounds for fish and other wildlife while helping to control stream erosion and sedimentation. The wetlands are designated conservation areas for their ecological services. Native swamps and marshes were also constructed in more than 20 different locations along the restoration, creating habitat for plants and animals. The restoration project increased the overall biodiversity of the corridor between pre-restoration work in 2003 and the end of 2008. The number of plant species increased from 62 to 308, the number of fish species jumped from 4 to 25, and the number of bird species from went from 6 to 36. The number of other species such as aquatic invertebrates, insects, mammals, and amphibians also increased at least two-fold.

The treatment of the edge creates a playful stream environment as ground and surface levels submerge and re-emerge according to the seasons. The terraced vertical walls allow access for pedestrians to come down into the corridor as water levels change and also provide flood protection for the city for up to a 200-year flood event.

The stream also helps to reduce the city's temperature because of the removal of the expressway, the ban of personal vehicles from the stream's periphery, the implementation of several public transportation options, the cooling effect of the running water, the increase in native riparian vegetation and canopy, an increase in

wind speed moving through the corridor. The stream as a breezeway also helped to decrease the likelihood of residents in the area to suffer from respiratory problems.<sup>417</sup>

Figure 55: Photo  
Source: Alexander Robinson<sup>418</sup>

---

<sup>417</sup> <https://www.scribd.com/document/14892153/Critical-Review-of-the-Cheonggyecheon>

<sup>418</sup> Alexander Robinson, Natural stones are used to both create walkways for pedestrians and to help regulate water speeds and levels and various points along the stream., digital image, Landscape Performance, accessed December 10, 2016, <https://landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration>.

Figure 56: Plan of Cheonggyecheon Stream  
Source: Platforma Urbana<sup>419</sup>

---

<sup>419</sup> Platforma Urban, Conceptual Plan., digital image, Landscape Performance, accessed December 10, 2016, <https://landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration>.

## **V      QUALITIES OF A UNITED LANDSCAPE**

## 5.1 PROBLEM STATEMENT

How can the inherent characteristics of the ancient Waikīkī ahupua‘a inform multidisciplinary design interventions for the Ala Wai Watershed’s infrastructure so that it strengthens the landscape identity, reconnects the urban to the natural, and mitigates hydromodification?

Problem	Solution	Catalyst for Identity
There is a physical disconnect between the urban and natural environment.	Strengthen the identity of the landscape.	The water is a <i>physical attribute</i> of the landscape that runs from mauka to makai as a parti throughout the landscape, connecting the physical and cultural aspects between the urban and natural environment.
Water is the backbone of Hawai‘i’s urban and natural environment and good water quality depends on a closed-loop system.	Embed natural elements into the urban environment to reflect commensality and raise an awareness.	The ahupua‘a evolved from <i>human activity</i> within the landscape. It encompasses stewardship, preservation, restoration, and consumption of the ecosystem services within a closed-loop system. It reflects awareness and commensality between the natural and the human environment.
The Ala Wai Watershed’s urban framework is vulnerable to disasters because of “hard” infrastructure.	Mitigate the effects of hydromodification by using green infrastructure.	The ancient Hawaiians derived <i>meanings and symbols</i> from the landscape to work in sync with it. Their infrastructure did little to alter the landscape and in fact improved the quality of water as it flowed down the ahupua ‘a.

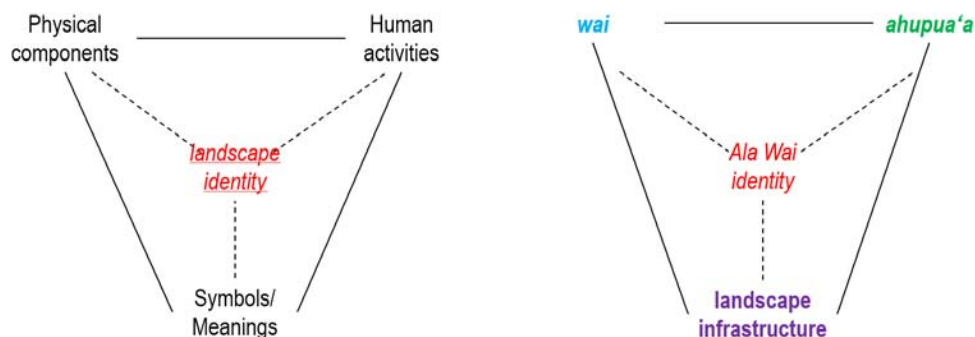


Figure 57: Landscape identity

Source: By Author

## ADDRESSING PHYSICAL CHARACTER

Manipulate the site's materiality.  
Creating an interest in the space.  
The ordering of elements.  
Creating a direction of movement.



ENGAGE THE VISUAL



ENGAGE THE LOGICAL

## ADDRESSING HUMAN ACTIVITY

Creation of areas for different user age groups and group sizes.  
"Playgrounds" to encourage use of the vicinity.  
Variations of movement- skip, crawl, spin.



ENGAGE THE VISUAL



ENGAGE THE BODY

## ADDRESSING MEANING

The use of place names.  
Symbols embedded within the spatial design.  
A distinctive plant palette reflecting culture and sustainability.



ENGAGE THE VERBAL



ENGAGE THE NATURAL

Figure 58: Design approach in relation to landscape identity  
Source: By Author



## **5.2 WATER MEMORY AND LANDSCAPE IDENTITY**

### **The Importance of Water in a Landscape's Identity**

Water is the sculptor of the landscape. Memory and cultural identity is linked to water. The ancient Hawaiians centered their society and their interpretations of the landscape to their collective memories of water, forming landscape symbols like mauka and makai, animating the water by giving bodies of water various names, and founding rituals like the kapu. In their reverence for water, they observed its role in their environment: as a provider, a sculptor, a design driver, and as a necessity in their daily life. Individuals had a thorough knowledge base and inventory of the ahupua'a's physical components and spiritual associations because of their constant study of their environment.

The language of Hawai'i developed in response to the natural environment. Water was the most sacred resource because of its symbol as the source of life. The ancient Hawaiians had hundreds, if not thousands, of words to describe water. Waikīkī, aptly named for its spouting waters, was a sacred site rich in mana (power) because of its many waters. The waters of Waikīkī were said to have healing properties, made agriculture and ocean harvests bountiful, and was a favored dwelling and recreational place for the ali'i and maka'āinana.

All the waters in Waikīkī held memories and informed the ancient Hawaiians. The water had defined identities within the landscape. This explanation will solely focus on the Mānoa Stream in conveying the identity of water and its role in the landscape.

### **The Stream that Change Names**

The ancient Hawaiians centered their society and their interpretations of the landscape to their collective memories of water, forming landscape symbols like mauka and makai, founding rituals like the kapu, and animating the water by giving bodies of water various names that sometimes changed. There were many streams and bodies of water that changed names, especially in the Waikīkī ahupua'a.

Beginning from the headwaters at the Ko'olau Ridge, there are seven tributaries that make up the Mānoa Stream. 'Aihualama, Waihi'inui, Waihi'iiki, Lua'alaea, Nāniupō, Wa'aloe and Waiakeakua. 'Aihualama stems from the area near the peak at Pu'u Pueo where legend says that the jealous Ka'uhi killed the beautiful Kahalaopuna, whom he suspected of having

an affair. When the gods realized the maiden was murdered, they made it rain everyday in her memory. The second is Waihi, which means trickling water. The third is Na niu‘apo, meaning the grasped coconut or beautiful bridge. The fourth is Wa‘a loa, which means long canoe. The famous female mo‘o Kihanui-lulu-moku (great island shaking god) lived here, making plants thrive in the stream. Queen Ka‘ahumanu made her home near the Wa‘a loa tributary. The last tributary to Mānoa is Wai-a-ke-akua, meaning ‘water used by god’ is because Kane and Kanaloa came to this tranquil pool after making Punahou spring. Kane left his footprint on the stone at the pool’s edge. The five tributaries converge and change their name into the Mānoa Stream. Mānoa and Pālolo converge deep in Waikīkī. At the point that they enter the flatlands of Waikīkī, the names changes.<sup>420</sup>

Mānoa Stream becomes Kalia Stream, named for the ‘ili which it runs through. Kalia means “waited for.” It’s current site is now is where Fort DeRussy Park is.<sup>421</sup> Pālolo Stream becomes Pahoa Stream. Kalia and Pahoa Stream join in an area called Hamohamo, but divide again into the Waikolu (three waters). The Kuekaunahi, ‘Apuakehau, and Piinaio Streams make up the Waikolu and are the three main streams that empty Waikīkī into the ocean.<sup>422</sup> The name Kalia changes when it enters a once a fertile area irrigated by the Pi‘inaio Stream which is now located between the Hilton Lagoon and Ilikai Hotel. The Piinaio Stream is a large delta like area before flowing into the sea, making the area ripe for the taro and fishponds.<sup>423</sup>

Kuekaunahi, which is to the ‘Ewa of Kapahulu Pier today, empties into the sea at Hamohamo. Hamohamo is between ‘Apuakehau and Kuekaunahi Streams from the Ala Wai to the ocean. Hamohamo means “soothing” or “rub gently” which may refer to the soothing waves rubbing or washing up gently on the sand.<sup>424</sup> Kaneloa which means long or tall man was for a tract of land that extended from today’s Kaneloa Road through Kapi‘olani Park between the Ala Wai and Kuhio Avenue. Kaneloa encompassed the zoo and was diverted into the Mānoa Pālolo Drainage Canal. The only reminder of the Kuekaunahi is a break in the reef offshore.<sup>425</sup>

---

<sup>420</sup> George Kanahale, *Waikiki 100 BC to 1990 AD : An Untold Story* (Honolulu: Queen Emma Foundation, 1995), 2-5.

<sup>421</sup> Veneeta Acson, *Waikiki: Nine Walks through Time* (Norfolk Island, Australia: Island Heritage, 1983), 16.

<sup>422</sup> Acson, *Waikiki: Nine Walks through Time*, 2.

<sup>423</sup> Ibid., 16.

<sup>424</sup> Ibid., 37.

<sup>425</sup> Ibid., 71,78.

Apuakehau, meaning “basket of dew,” was located near the Outrigger Waikīkī Hotel, was also referred to as Muliwai o Kawehewehe and exits into the ocean at Helumoa.<sup>426</sup> Kawehewehe “the removal” or Muliwai “pool or estuary left by tides” was a place where the sick and injured people were brought for the curative baths in the tide pools.<sup>427</sup>

Helumoa means “chicken scratch.” It was home to the local aliʻi and later became the royal residences to the Hawaiian monarchy from Kamehameha onwards. There were also heiaus located here, one of which was Apuakehau.<sup>428</sup> Apuakehau Stream was characterized by freshwater streams and pool where people could rinse after swimming or surfing.<sup>429</sup> Kaluaokau, the present location of the International Marketplace is where the Apuakehau stream used to flow through.<sup>430</sup> To the west of Apuakehau stream, a place called Kahaloa meaning “long place was used for spiritual renewal” where ancient Hawaiians would bathe and be healed.<sup>431</sup>

---

<sup>426</sup> Ibid., 37.

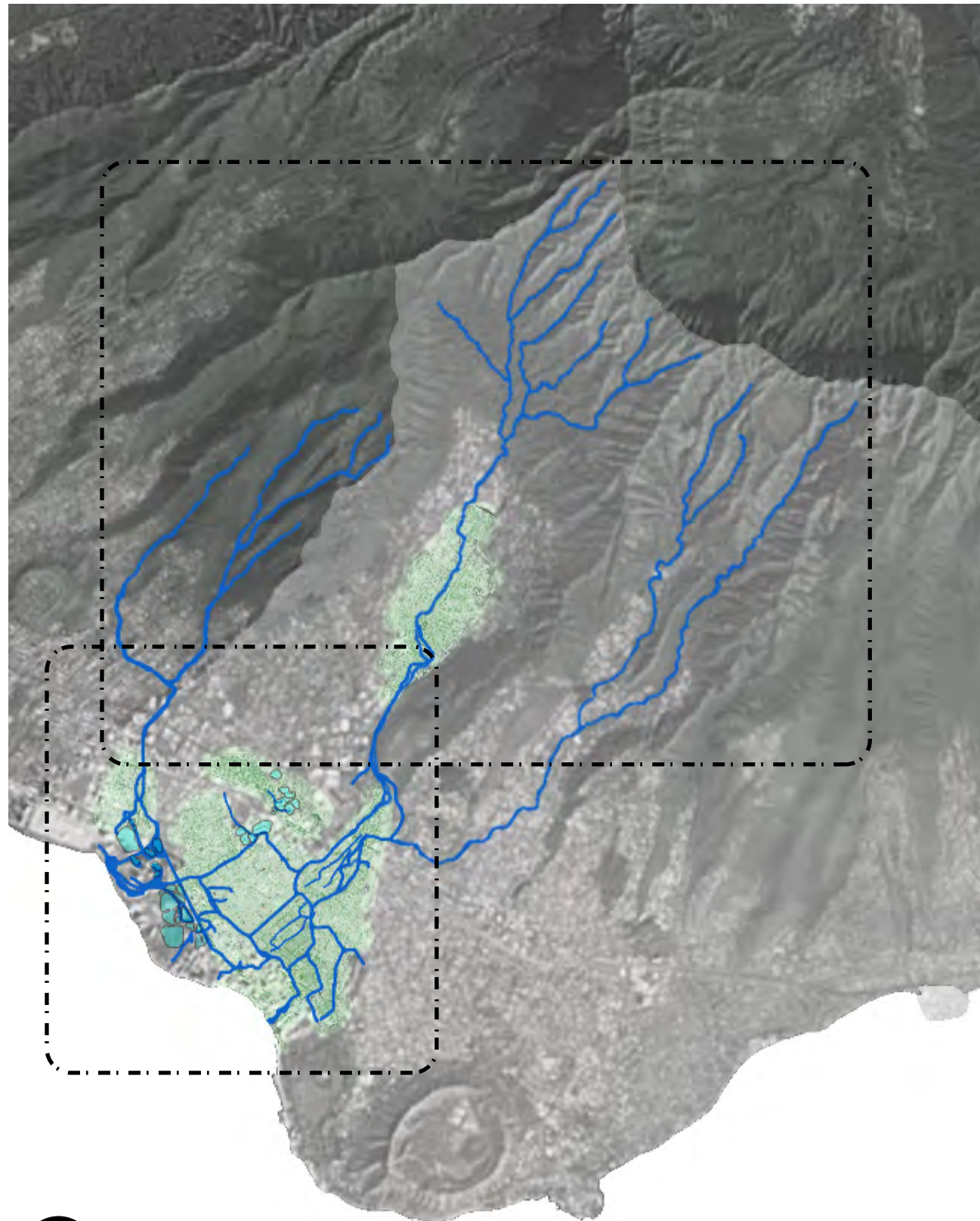
<sup>427</sup> Ibid., 103.

<sup>428</sup> Ibid., 32.

<sup>429</sup> Ibid., 36-37.

<sup>430</sup> Ibid., 46.

<sup>431</sup> Ibid., 106.



## THE STREAMS THAT CHANGE NAMES



### **The Water's Edge and Human Activity**

The importance of the water's edge and the waterfront in the Ala Wai Watershed cannot be overlooked as part of the importance of water. The water's edge determines the transition from water to land and plays a critical role in the human and water interaction. The waterfront provides the largest public space nestled between the urban setting and the natural environment. It is an area for habitat, for recreation, for contemplation, and for excitement. Preserving and enhancing the area between land and water strengthens the Ala Wai Watershed landscape in its physical characteristics, in the memories people who use the site have and will have, and the current and future meanings that these places should have when the edges are defined and enhanced.

### **Water is the Catalyst for Change**

All the waters in Waikīkī hold memories and have their own identities that correlated with their physical characteristics, their services to the people, and the myths and legends associated with them. They sculpt the landscape physically, socially, and psychologically. Today, these streams that changed names are modified—either buried, diverted, polluted, or a combination of all. It is important to incorporate water in the design of a solution. The design solution should center around water because it is the unifying element in the mauka to makai landscape. Combinations of certain aspects of water's characteristics, along with different edge conditions that were described in the research portion of the dissertation will serve as a generative design tool in the eventual appearance and integration of water within the urban environment.

## **5.3 WATERSHED MODEL AND MANAGEMENT**

### **The Importance of the Ahupua‘a in Society**

The ahupua‘a was important because it is how the society related to their surroundings. The Hawaiians used their understanding of the landscape to create their society. Hawaiian watersheds are unique to the islands so the indigenous watershed model the created is also unique to the environment. The ancient Hawaiians’ watershed management reflected the somatic and filial relationship they had to their landscape and is based on respect for nature. They structured their society and political system to be in-sync with their natural environment because they understood that dependency on their surroundings. The indigenous land management practice was sophisticated, evident of its capability to support and sustain a society over a thousand years.

The ancient Hawaiians were observant of their environment. Through oral tradition and memorization, individuals had a sublime, multi-faceted knowledge of their ahupua‘a. Culture is the transmittal of social and ecological information down through the generations. The conveying of information in the Hawaiian society through the generations was broken because of the pestilence that killed many native Hawaiians. While the indigenous knowledge is forgotten, the ideas of stewardship and accountability can be continued today through best management practices in today’s local level society: the community, in the neighborhood, and in the home.

### **Management of the Ahupua‘a**

The Hawaiians’ political system was strict, but it placed extreme importance on the protection of the natural environment. The kapu structured the ancient Hawaiian society into a hierarchy that paralleled the structure of their land management model. The ahupua‘a was managed at a localized level where residents could monitor and enhance the stream network and could produce sufficient amounts of goods for themselves and taxation without overwhelming the watershed.

No one owned the land, and the fact that it belonged to the gods made it sacred. Everyone in the society, ali‘i or maka‘āinana were held to a high standard of responsibility for their use of the ahupua‘a. The enforcement of the kapu which punished the misuse of the ahupua‘a’s resources functioned to preserve natural resources so that future generations could

also prosper. Today, ownership of the Ala Wai Watershed is divided among many entities and individuals. Management and maintenance of the watershed is therefore “fragmented amongst several government agencies and private land owners”<sup>432</sup> instead of a singular entity with a hierarchical approach that starts at the island level.

### **A Closed-Loop System**

Prior to the 1800s, the Waikīkī ahupua‘a had three ecological zones that functioned as a closed-loop system: the upland rainforest, the midland agriculture fields and settlement, and the coastal marshes and aquaculture lands. The upland rainforest and the coastal marshes functioned to filter the water in its path to the human settlements and its release into the ocean. The human settlements in the midlands also prioritized the quality of water by implementing strict laws on water use. Currently, 64% of Hawai‘i streams have become impaired by pollution, 98% of drinking water is sourced from the ground and the islands’ overall fresh water supply is decreasing and its quality is not potable.<sup>433</sup> Upland rainforest degradation, hydromodification, and coastal urban development are detrimental to the prosperity of the entire state of Hawai‘i; not just the Ala Wai Watershed. Today’s upland forest is deficient in filtering and soaking up water and the coastal marshes are gone, leaving a hole in the system.

---

<sup>432</sup> Townscape, Inc. and Eugene Dashiell, *Ala Wai Watershed Analysis Final Report*, 27.

<sup>433</sup> State of Hawai‘i Department of Agriculture, "History of Agriculture in Hawai‘i."

## 5.4 APPLICATIONS OF LANDSCAPE INFRASTRUCTURE

### The Importance of Green Infrastructure

Green infrastructure needs to become part of the Ala Wai Watershed's framework because it is vulnerable to even the smallest system failure. The urban watershed's current infrastructure today is successional, only changed or reinvented when the technology is obsolete or malfunctioning. The unpredictability of flooding in the watershed shows that the current infrastructure needs to be redesigned to be responsive, flexible, and adaptable to small or big disasters. The current management model for the infrastructure is also too centralized. Indigenous examples of successful watershed management models are decentralized and managed at a local level.<sup>434</sup>

In Hawai'i's current watershed management system, attention has turned to the value in rethinking man-made infrastructural systems because of small failures like water-main breaks and several highly visible catastrophic collapses like sewage spills. It is especially hard to predict infrastructural damages because it is often hidden from view, so near-malfunctions cannot be detected, and malfunctions are not immediately apparent.

Natural infrastructure is a visible infrastructure that should "perform what urban infrastructure does, should have the ability to remediate and reverse adverse effects of hydromodification, and should be able to accommodate the growth or shrinkage of the urban environment."<sup>435</sup>

### Problems to Address

The infrastructural interventions proposed in this dissertation address physical, social, and symbolic problems at the extent of the conceptual and are not meant to be technical solutions to hydromodification. Also, this dissertation does not address every single negative effect of hydromodification. The design solutions will focus on three aspects: stormwater runoff management, water quality improvement, and stream restoration.

---

<sup>434</sup> SWA Case Study 17.

<sup>435</sup> SWA Case Studies 17-19.



### **Focused Applications of Natural Infrastructure in the Ala Wai Watershed**

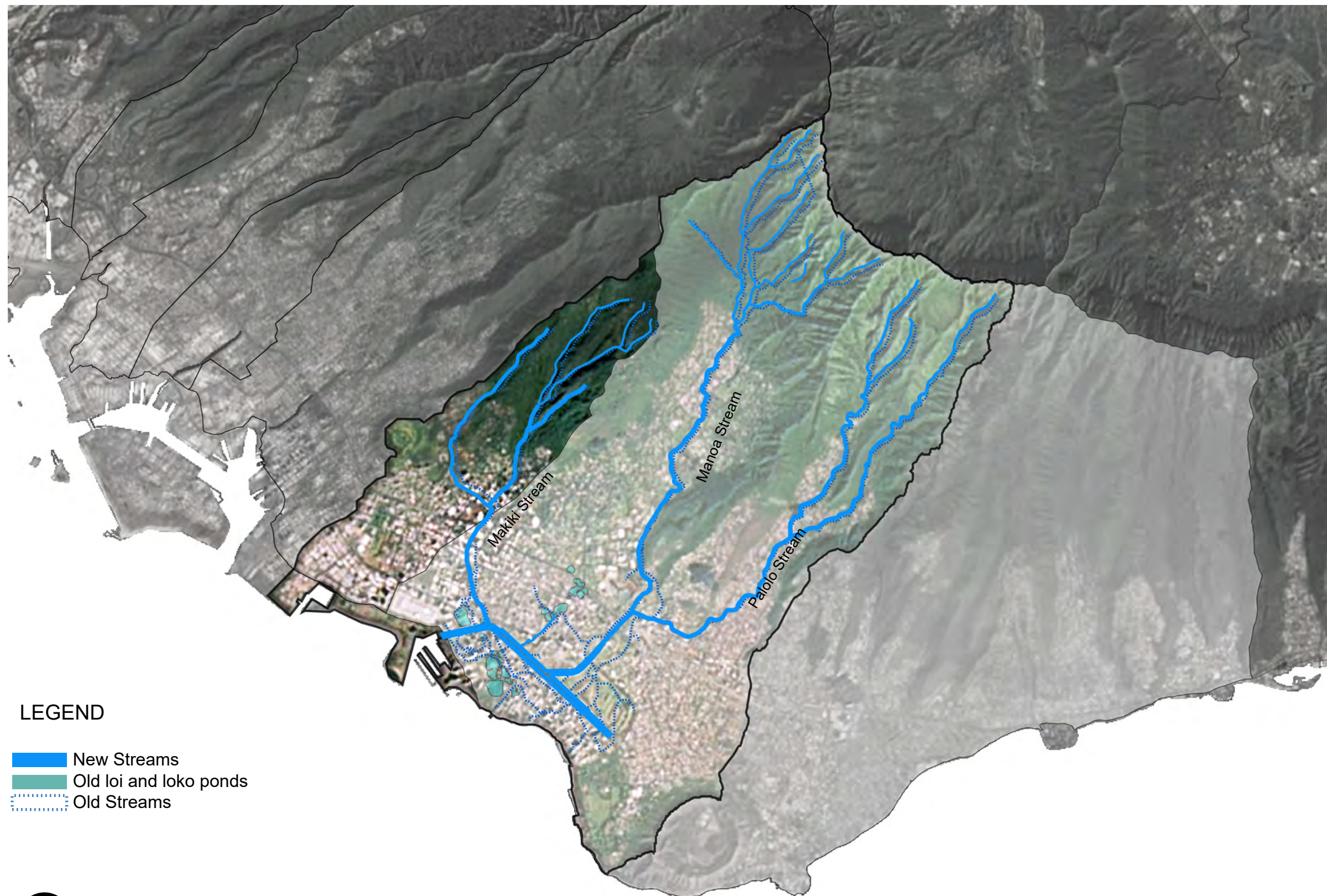
In addressing the problems of hydromodification in the Ala Wai Watershed, the focus of green infrastructure will be to create a closed-loop system—mimic nature to filter, soak up, and store water on site and minimize the amount of surface water being taken off-site. The two parts of the ahupua‘a’s ecological zones that played roles in filtering, sponging, and holding water were the *wao akua* upland rainforest and the *kaha kai* coastal wetlands, however the urban fabric can also play a vital role in addressing the problems of hydromodification.

The design solution will focus on applications of natural infrastructure in the form of (1) re-vegetating or re-foresting patches adjacent to the stream to extend the upland rainforests within the urban landscape, (2) re-constructing wetlands on transitional edges before they enter receiving waters, and (3) embedding natural infrastructure within the urban setting.




## **VI      DESIGN APPROACH AND APPLICATION**

The interventions proposed in this dissertation address physical, social, and symbolic problems at the extent of the conceptual and are not meant to be technical solutions to hydromodification.

## **6.1 SITE ANALYSES**



LEGEND

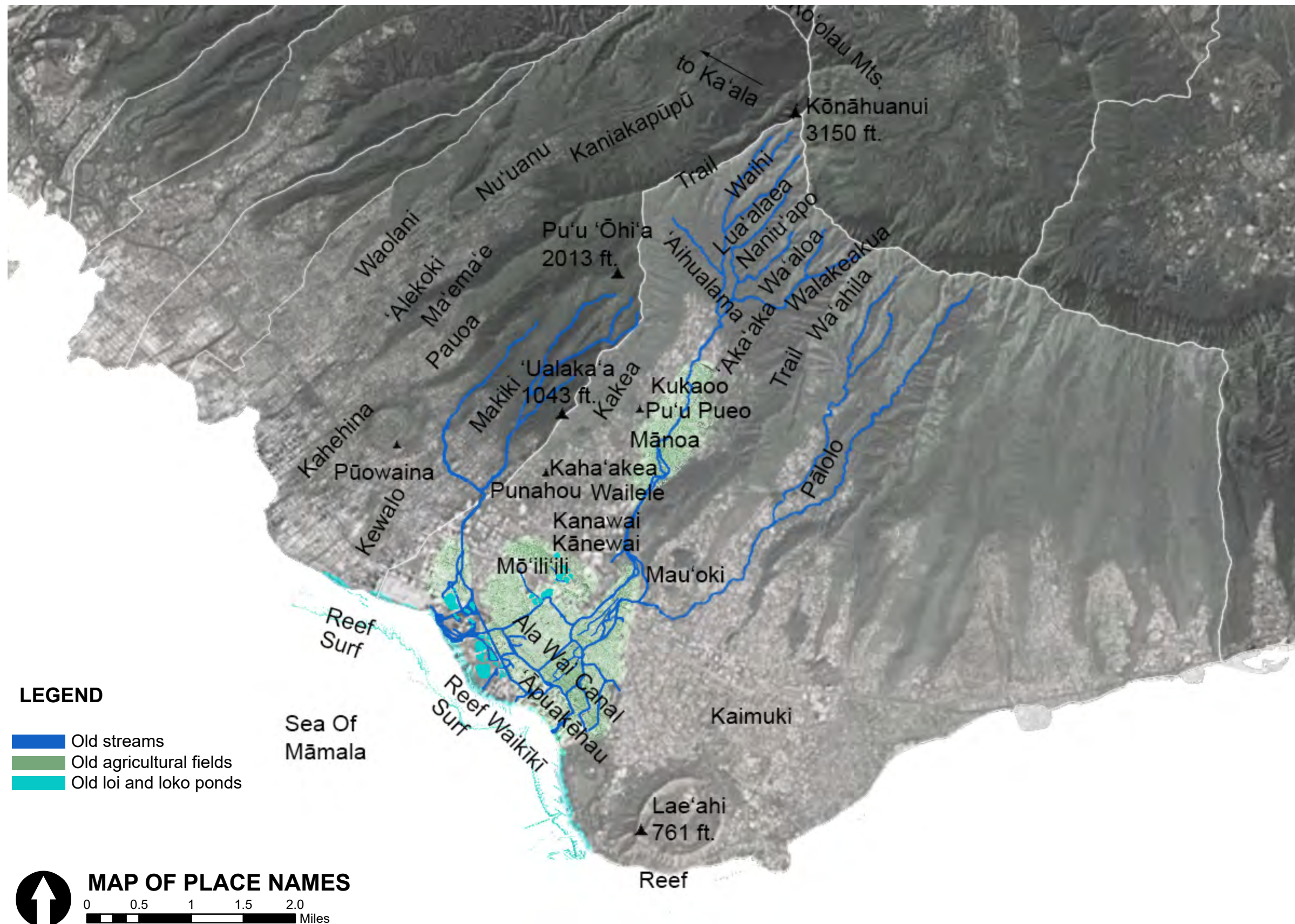
-  New Streams
-  Old loi and loko ponds
-  Old Streams



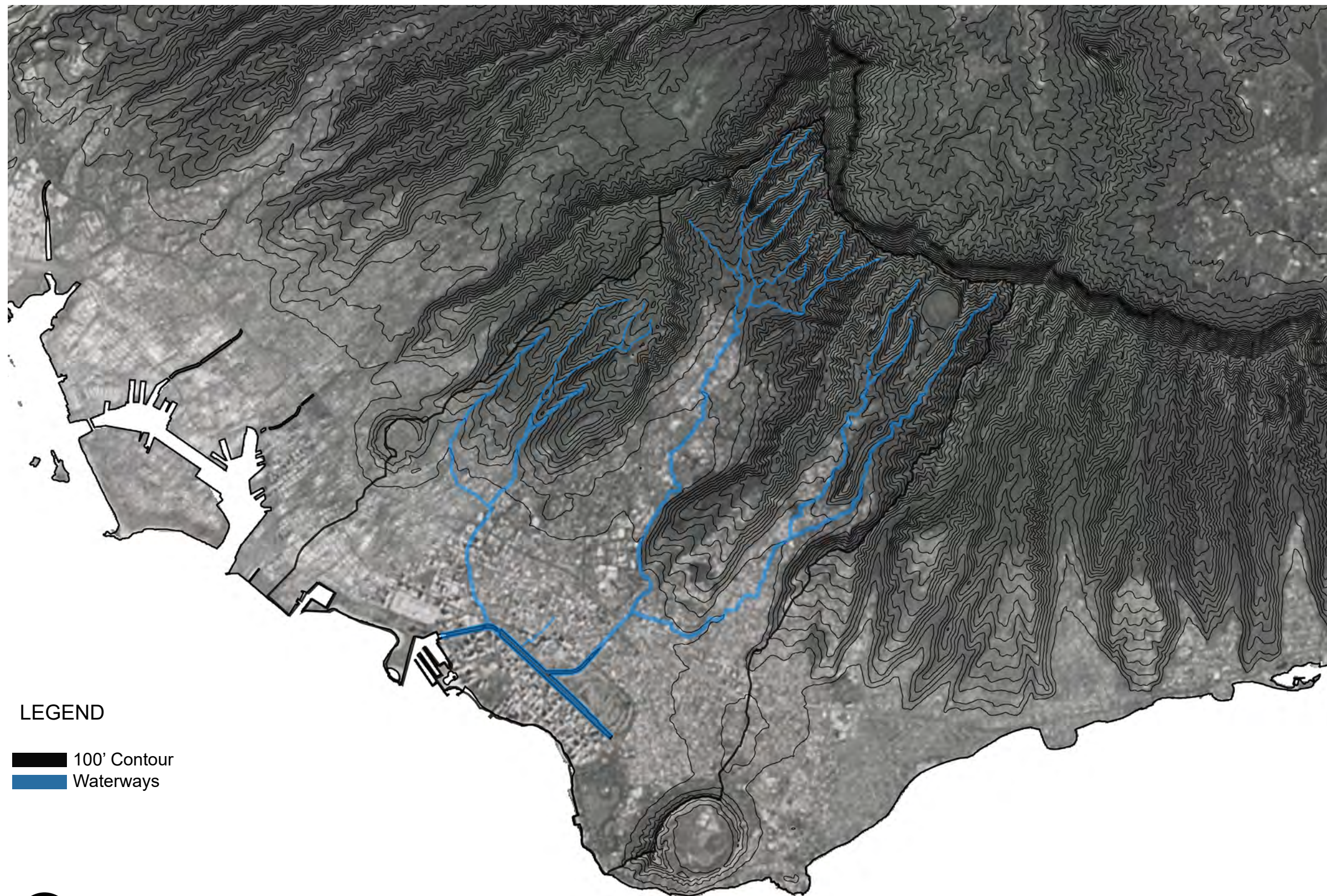
OLD STREAMS AND THE NEW STREAMS

0 0.5 1 1.5 2.0  
Miles



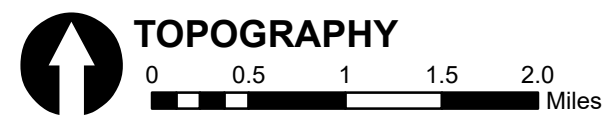




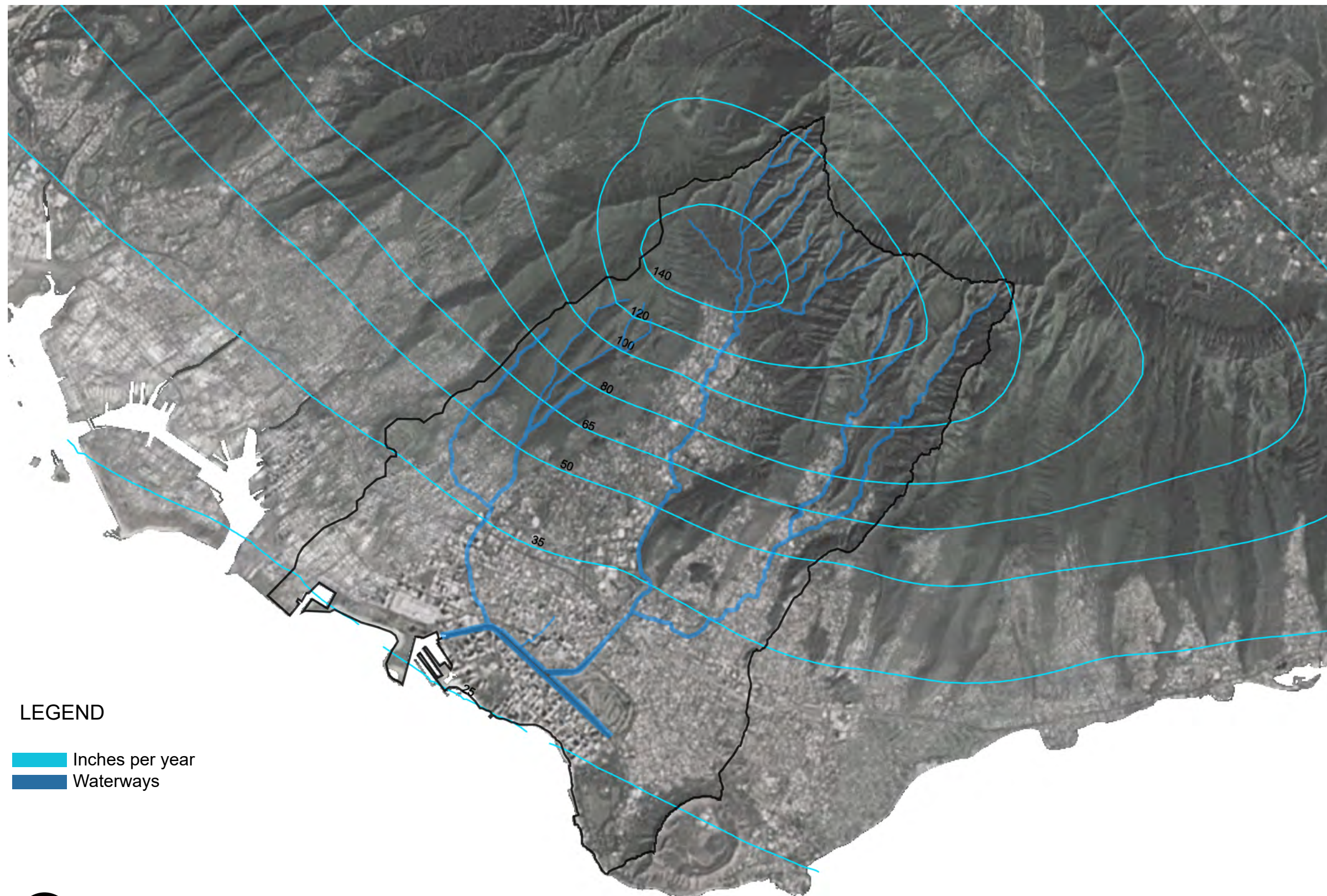


LEGEND

- 100' Contour
- Waterways

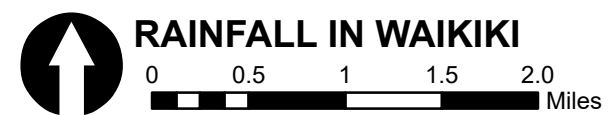




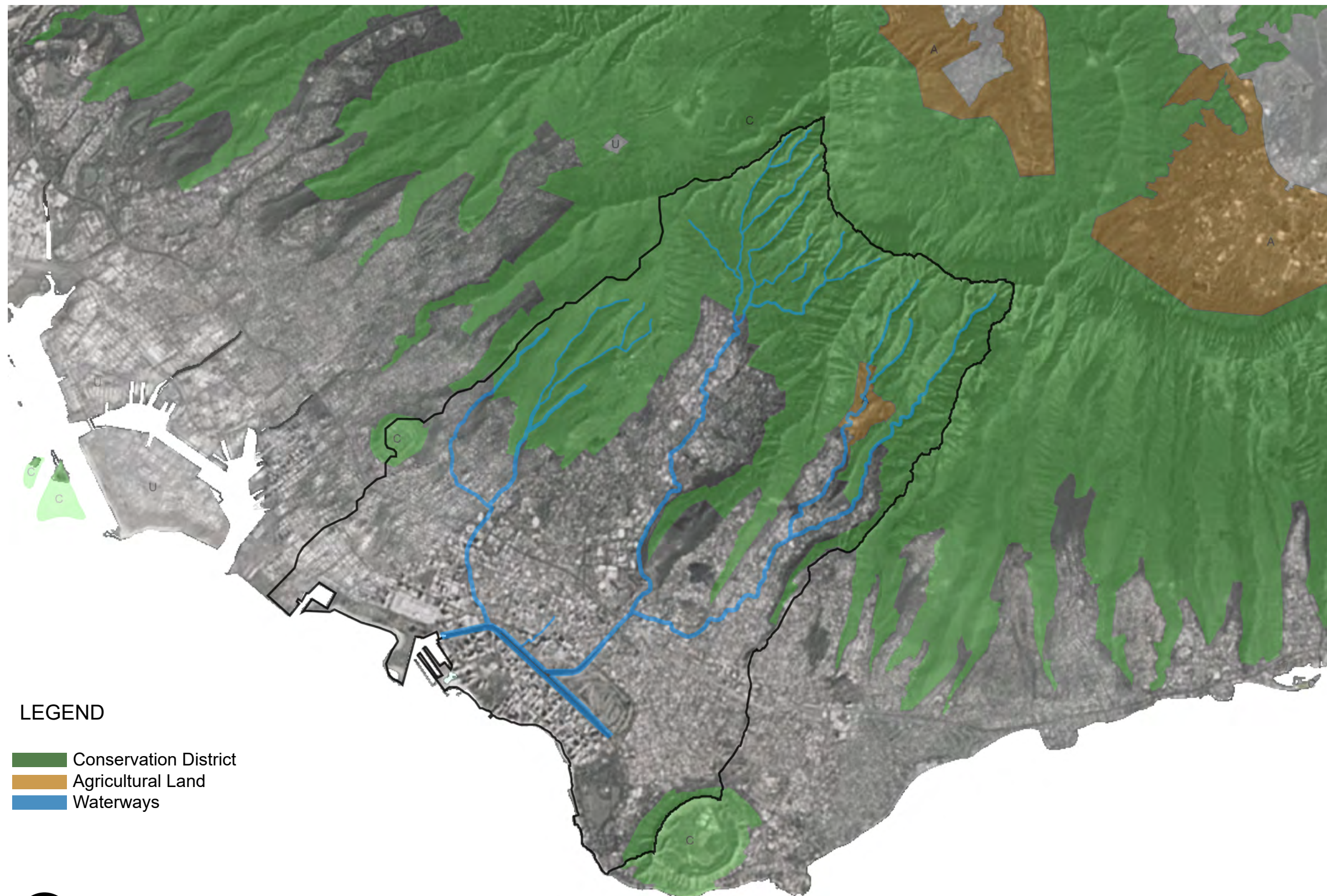


# LEGEND

- Inches per year
- Waterways

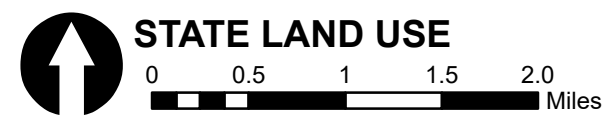




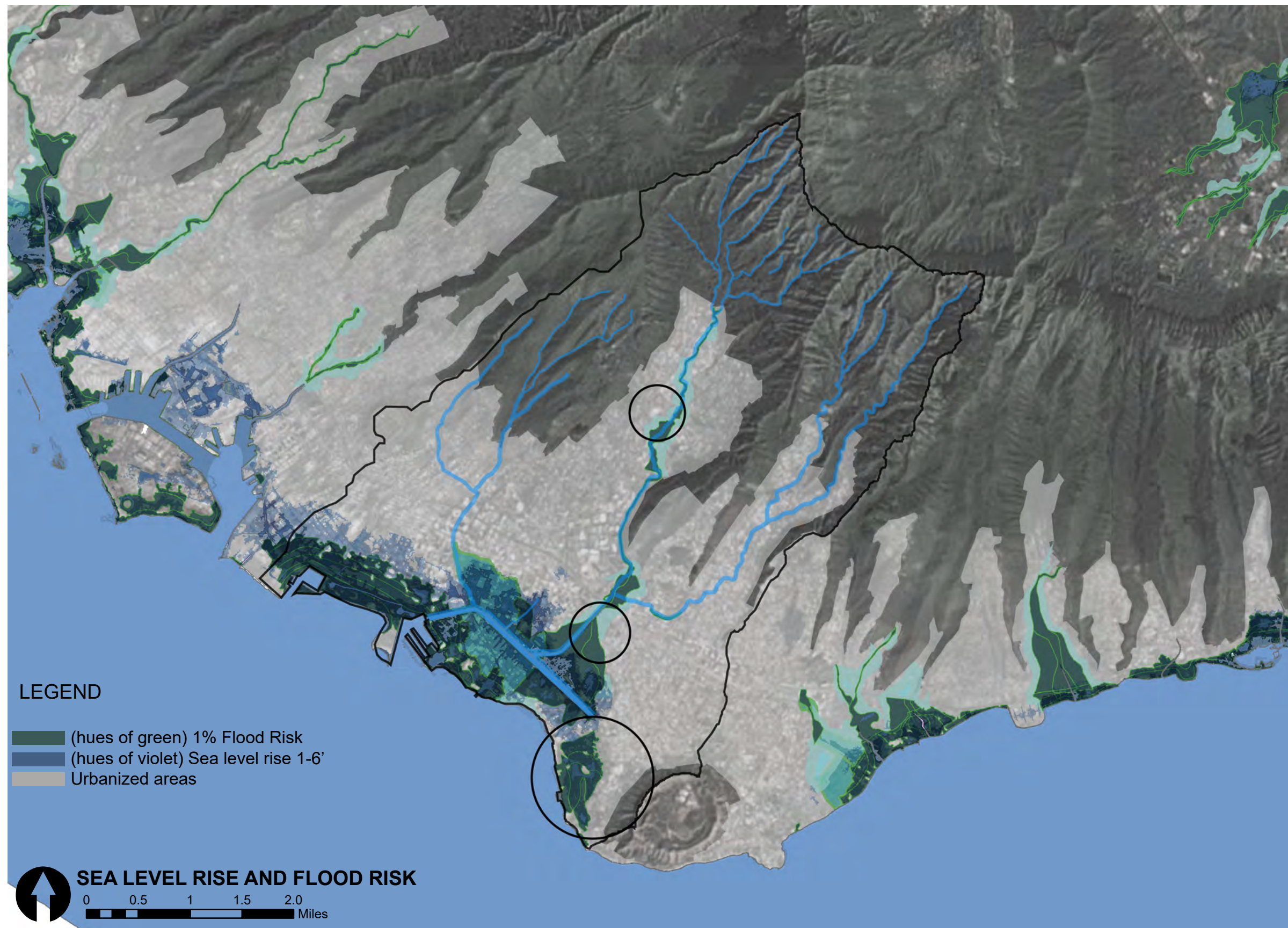


LEGEND

- Conservation District
- Agricultural Land
- Waterways







## 6.2 ALA WAI WATERSHED

Memory and Identity	Ala loa trail from mauka to makai to contrast the disconnect that the Ala Wai created.
Social Attributes	Pedestrian and bike paths to connect three sites.
Physical Application	Low impact development (LID) for stormwater management.

### **Memory and Identity: Ala Loa**

#### **A mauka to makai corridor**

Transportation and communication in ancient Hawai‘i was through major trail systems called ala loa (long trail). They were extensive networks running through the entire island providing for social and economic interaction between different villages or settlements. The ancient Hawaiian trails were usually single-file footpaths lined with smooth stepping stones that followed the topography.

The trails enabled the gathering and trading of resources between the upland and coastal zones in the ahupua‘a or across the island, between other ahupua‘a. Ali‘i located their royal courts along the ala loa and often used them to circle their islands to deal with affairs. Tax collectors used the ala loa as well to collect tribute at each pig-altar of the ahupua‘a they were responsible for.

After the Westerners arrived on the islands, the trails evolved to meet infrastructural changes. The trails eventually widened to accommodate horses and horse carts. Today, most of the ancient ala loa and mauka-to makai trails are extinct or disconnected. The ones that are still in existence are the trails that serve as public trails for hiking, camping, biking, and hunting.

In commemorating the ala loa, we highlight the relationship of water to the landscape by creating a physical connective axis from mauka to makai; a contrast to the disconnect that the Ala Wai Canal created. The approach to a modern-day ala loa includes a green trail that parallels the Mānoa Stream and follows the path of the water (ala o ka wai). The trail will

connect to three proposed sites along the Mānoa Stream that express significant mythological narratives or legends of the places in which they occur.

### **Social Attribute: Site Connectivity & Recreation**

#### **Site connectivity and recreational nodes**

The green corridor will link three proposed sites that contain natural, cultural, and recreational resources along the Mānoa Stream through a “streamwalk”, a pedestrian and bike path along the 7 mile long Mānoa Stream. The design of the trail is meant to bring cultural awareness, encourage recreation, and introduce a connection between the wao kanaka urban areas to the wao akua natural environment.

The corridor will host a matrix of landscapes within different nodes along the stream that support a range of activities. The activities at each node will differ with the intent to appeal to the population adjacent to the node and to provide different experiences and create memories.

### **Physical Application: LIDs**

#### **Stormwater management strategies**

Because of the nature of urban cities, a single design intervention will not be able to handle the demands of good water quality and pristine stream environments. The management of water must be a holistic design endeavor that encompasses more than areas immediate to the stream. In order for the Ala Wai Watershed to truly be a beautiful green ahupua‘a as it once was, the whole watershed needs to be a system of natural infrastructures that work to harvest rainwater, buffer pollutants, retain water on sites, allow infiltration of rainwater among others. The goal of the infrastructures should be that by the time the water running from the mountains then to the urban areas reaches the stream, it should be clean.

Low impact development (LID) systems will be implemented as part of the watershed’s overall stormwater management. LIDs provide a number of uses and benefits in draining water away from areas, in addressing water quality and in protecting the natural environment. In contrast to the conventional, engineered stormwater management strategies that are designed to convey stormwater as quickly as possible to the nearest stream or canal, LIDs are designed to store water for later use, to treat water, and to allow it to infiltrate the soil. LID systems will be proposed throughout the watershed in two scenarios: (1) LID systems adjacent to a selected site,



and (2) LID strategies for streets that lead directly to a body of water. The different types of LIDs complement each other as they all function towards the improvement of water quality and water infiltration.

Figure 59: Types of LID strategies to mitigate stormwater runoff.  
Source: By Author

#### Bioswales

Bioswales, like other LIDs minimizes the amount of pavement and maximizes rainwater infiltration. Bioswales consist of shallow planted depressions with gently sloped sides. They are filled with either vegetation, compost and/or riprap. Stormwater flowing down

impermeable pavements can enter the bioswales through curb cuts and openings. Bioswales hold or trap the water that flows across the urban landscape, filters the water and allows it to infiltrate the soil beneath. Bioswales can also be found in front or backyard gardens and make for beautiful landscaping elements. Much like a bioswales, a rain garden is a built depression planted with vegetation that allows stormwater from hardscape to collect, briefly settle, then infiltrate into the ground.

### Green Roofs

While rooftops aren't on the ground level, nevertheless, they represent a large portion of the impervious surfaces in an urban setting. A green roof has plants and a soil bed that absorbs rainwater and evaporates it. Most of the rain water that falls on a green roof is stored in the planting bed and then taken up by the plants. Through transpiration and evaporation, it is returned to the air. Green roofs also cool the temperature of the water and excess water from the roof is filtered by the plants and soil before reaching the ground.

### Permeable Surfaces

Sediment and pollutants build up on impervious surfaces like sidewalks and roads. When it rains, pollutants are washed and carried into storm drains which empty into stream, leading to its impairment. Not all hardscapes need to be concrete or asphalt. Exchanging impermeable surfaces pavement with a surface that allows stormwater to settle, seep, or infiltrate will greatly reduce the amount of stormwater runoff flowing across a landscape and into the nearby stream ecosystem. Permeable surfaces include rain gardens, bioswales, filtration strips, and permeable pavement. In areas that need to be paved, there are many examples of pervious pavement like footpath stones, gravel, bricks, pavers, and grass paving cells.

### Stormwater Ponds

Water from roofs and storm drains can be directed into a storage vessel to slow down its eventual entry into streams. Retention and detention ponds can play an integral role in holding the water. The main difference between a detention and a retention pond is whether or not it acts like a traditional pond with a permanent pool of water. The amount of water in a stormwater pond is controlled by the water table and also through the outlet structures. The

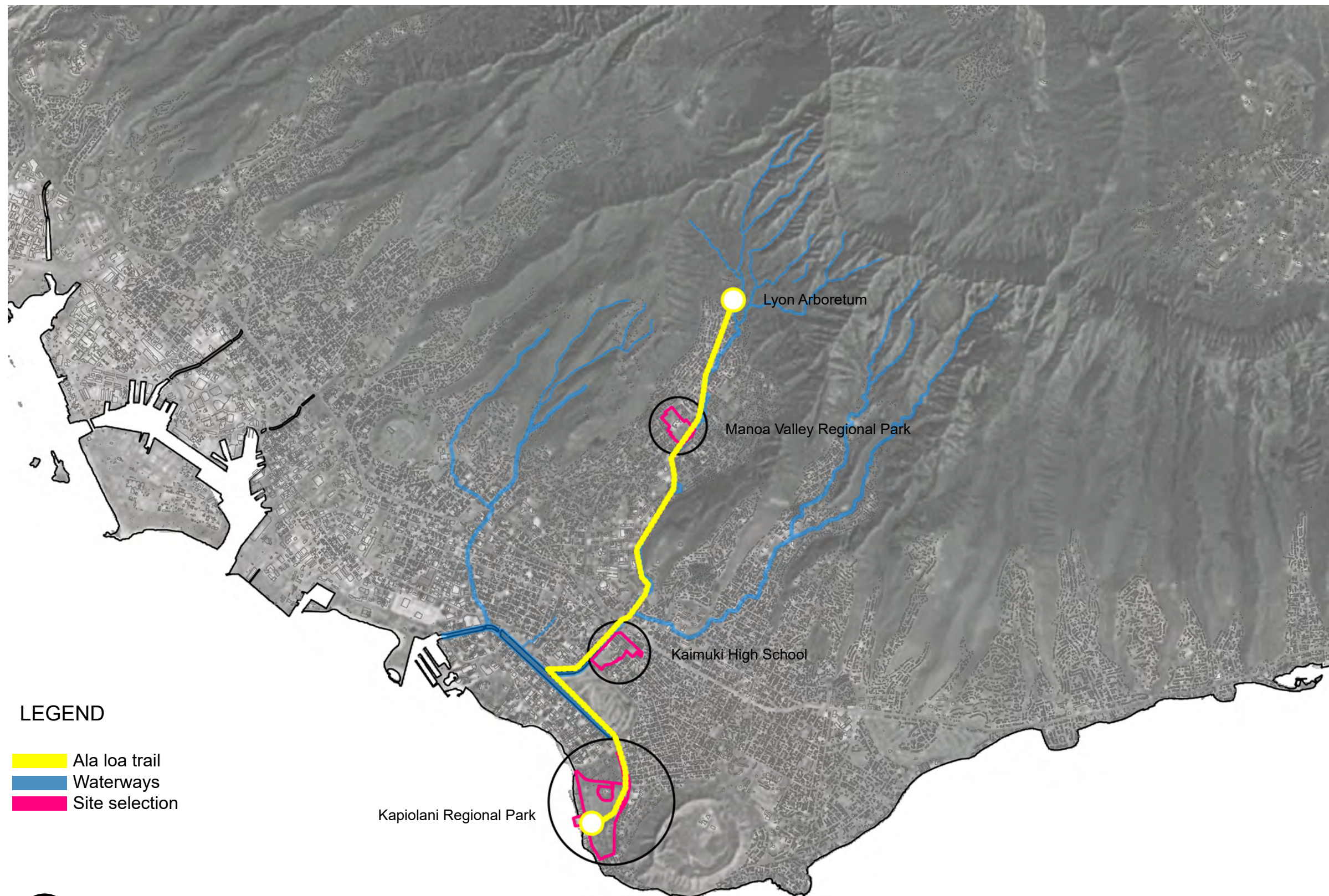
basins store and attenuate stormwater runoff. They also provide water quality benefits by allowing sediments and pollutants to settle in their beds.

### Native Planting

The upland forests of Hawaii were repopulated to preserve the watershed. Reforestation efforts during the first decade of the twentieth century 800,000 acres of state and private land were replanted, but with non-native species. To re-establish the landscape's identity physically and symbolically, native planting should be implemented wherever possible instead of non-native species. Below is a list of endemic and indigenous plants that could be implemented in the landscape. The collection is arranged in groundcover, shrubs, and trees.

Ground Cover		Shrubs		Trees	
Aeae	Kalo	Akia	Maohauhele	Aalii	Maile
Akiaki	Kawelu	Kuahiwi	Ohia Ai	Ahakea	Maia
Akoko	Ki	Akiohala	Olona	Aiea	Manono
Akulikuli	Kupukupu	Ape	Papala	Akia	Milo
Alaala Wai	Olena	Awa	Pawale	Alahee	Naio
Nui	Palapalai	Awapuhi	Pia	Iliahi	Niu
Alula	Pau o Hiiaka	Hala	Pohinahina	Kauila	Noni
Awikiwiki	Pili	Hau	Poola Nui	Kawau	Ohe
Bonamia	Pohuehue	Hinahina	Popolo	Koa	Ohia Lehua
Menziesii	Uala	Ewa	Pua	Kopiko	Ulu
Hapuupuu	Ukiuki	Hoawa	Pualoalo	Kou	Wiliwili
Ihi		Ihi Molokini	Pukiawe	Kukui	
Iliihi		Iliau	Ulei	Loulu	
Ilima		Iliee			
Ipu		Kokia			
		Kokio Kea			





# LEGEND

- Ala loa trail
- Waterways
- Site selection



## ALA LOA AND SITE SELECTION

0 0.5 1 1.5 2.0 Miles



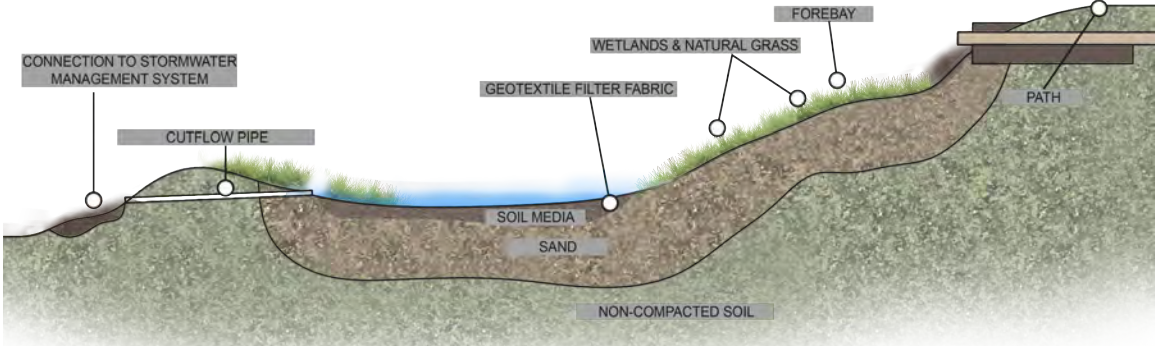


Scenario: Sites that are adjacent to a park or a large open space.

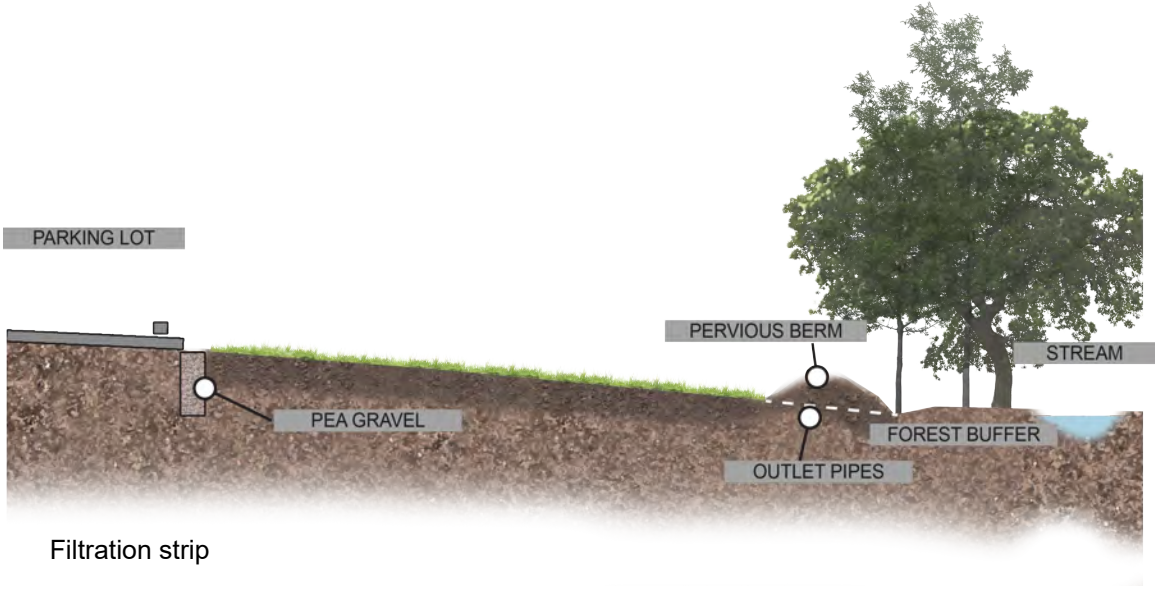
LEGEND

- Collection streets with filtration LIDs
- Rain gardens
- Stormwater ponds
- Water flow

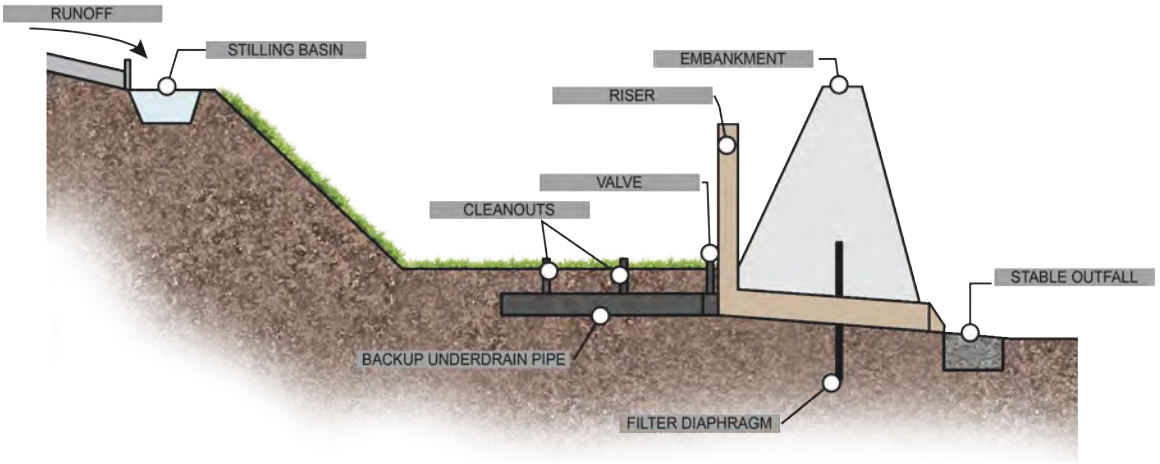
LID STRATEGY FOR THE WATERSHED



Detention pond



Filtration strip



Infiltration basin





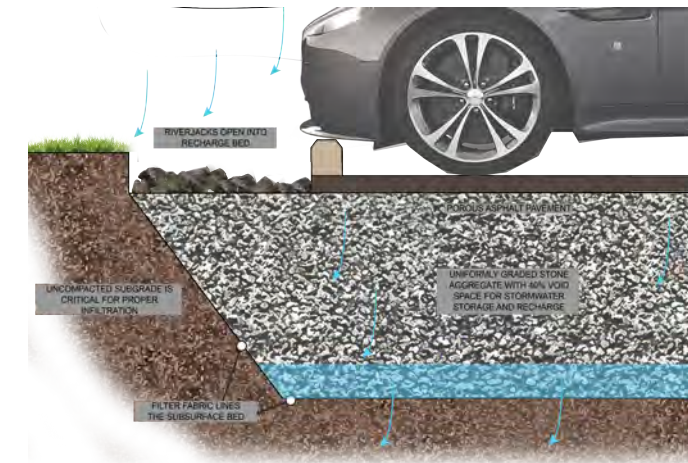
Scenario: Sites that are directly adjacent the stream.

## LEGEND

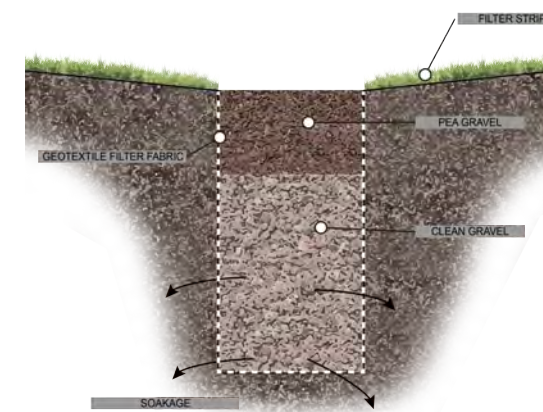
- Collection streets with filtration LIDs
- Green roofs
- Residential rain gardens
- Public gardens



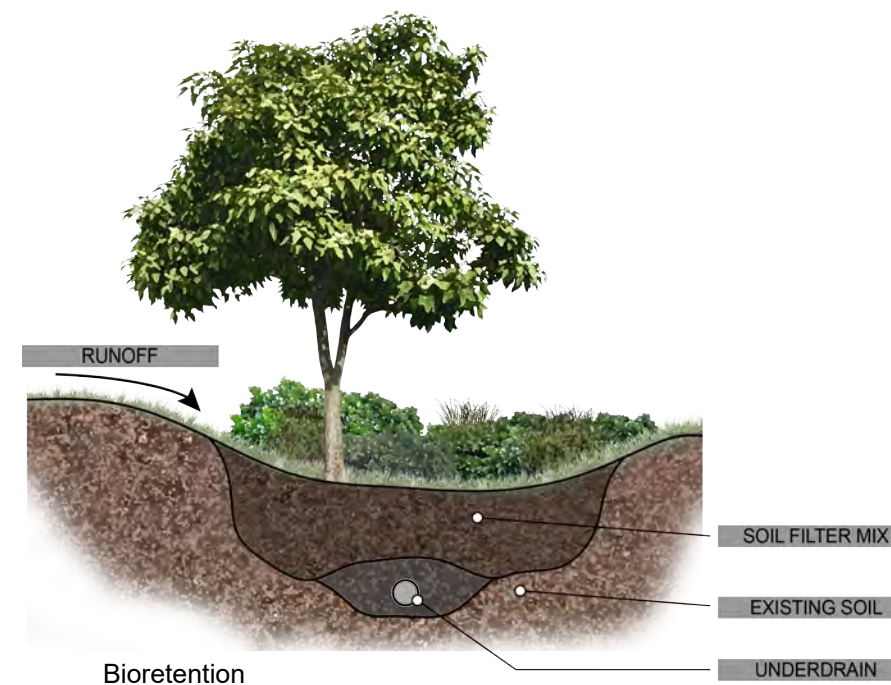
**LID STRATEGY FOR THE WATERSHED**



Pervious pavement



Filtration Trench



## 6.3 MĀNOA VALLEY REGIONAL PARK

Memory and Identity	The landscape speaks through stories. The story of Kahalaopuna describes the Mānoa Valley.
Social Attributes	Sports complex, leisure walks, running, biking, and cultural plant gardens.
Physical Application	LIDs, reforestation, site materiality, native plant palette

### **Memory and Identity: Kahalaopuna**

#### **Mo'olelo o ka Kahalaopuna**

There are many mo'olelo, or legends, associated with Mānoa Valley. The story of Kahalaopuna is a well known legend of how the Mānoa Valley came to be. This particular legend accounts descriptions of the streams and rivulets through the valley and several native plant species that were found within before urbanization. The narrative of the legend will be used in the design of a walking path that takes users throughout the re-forested Mānoa Valley Regional Park. The plant palette will be according to the succession of plants that appear in the legend's text, as seen below:

According to Hawaiian mythology, the Mānoa Valley was blessed with beauty because of the union of wind and rain. In Thomas G. Thrum's 1907 *Hawaiian Folk Tales*, the tragic story of the Princess of Mānoa, Kahalaopuna is told.

'Aka'aka (laughter) was a spur of the Ko'olau Mountains located at the head of the Mānoa Valley. 'Aka'aka formed the ridge running above Waiakeakua, one of the rivulets that feed into the Mānoa Stream. Waiakeakua means "the water of the gods." 'Aka'aka was married to Nalehua'aka'aka (the lehua on the brow of 'Aka'aka). The two *akua* had twin children: Kahaukani (wind), a boy, and Kauakuahine (rain), a girl. The children who were brought up separately by foster parents were ignorant of their relationship. They were united in marriage and had a girl they called Kahalaopuna. Kahalaopuna was the most beautiful woman of her

time. Thus, the union of wind and rain created beauty, for which the Mānoa Valley is noted for.

Kahalaopuna lived in a house at Kahaia mano which was on the road leading to Waiakekua. The house was surrounded by a fence of auki (dracaena). When Kahalaopuna reached adulthood, she was so exquisitely beautiful that no one would dare approach her. Rumors of her beauty spread throughout the valley and throughout the islands. Two men, Kumauna and Keawaa, both of whom were disfigured, heard about her beauty. They had never seen Kahalaopuna but they fell in love with her from the rumors. Because of their disfigurement, they did not dare to approach her as prospective husbands. Instead, they adorned themselves with leis of maile, ginger, and ferns, which they pretended to be love-gifts from Kahalaopuna. They would also go to Waikolu boasting lies of their conquest of Kahalaopuna. Rumors about them gradually reached Kauhi, Kahalaopuna's fiancée. He heard and believed them because the rumors were repeated so frequently.

The jealous Kauhi determined to kill her without evidence. He traveled towards Mānoa, stopping at Mahinauli, in mid-valley, where he rested under a hala tree that grew in a grove of wiliwili.

When he arrived at Kahalaopuna's house at Kahaia mano, he told her to prepare herself to accompany him in a ramble about the woods. She prepared and followed him till they came to a large stone in Aihualama, when he turned abruptly and sighed, saying, "You are beautiful, my betrothed, but, as you have been false, you must die." Kauhi killed Kahalaopuna but as soon as he was gone, a large owl, who was a deity, and a relative of Kahalaopuna began to dig the girl's body out. The owl took pity and breathed into the girl's nostrils to revive her.

In the remainder of the legend. Kauhi attempts to kill Kahalaopuna several times and she is resurrected each time. In the end, Kauhi paid with his life for the injustices that he committed towards Kahalaopuna.

### **Social attributes: Pu'uhonua**

#### **Coupling recreation and ecological services**

The Mānoa Valley District Park will continue to function as a sports complex, but also as an ecological sanctuary, a place for water filtration and infiltration, and a floodable plain. The proposed program is meant to couple the existing recreation with ecological services to make for a wholesome park design that services the environment. The existing programs of

the site include the Mānoa Valley District Park, the Mānoa Elementary School, and the Mānoa Gardens Elderly Housing. The school and the elderly community are not part of the design intervention, but they are the direct users of the district park. The recreational services offered by the sports complex such as swimming, tennis, running, baseball, softball, and basketball cater to teenagers and adults as well. An existing pedestrian path along the stream caters to leisurely walkers and dog owners. The proposed additions to the program include an observation area, constructed wetlands, new footpaths throughout the park, and a cultural garden.

### ***Physical Applications: Reforesting and the Park & Retaining Water***

In the ancient ahupua‘a, the upland rainforests in Waikīkī evolved over millions of years to be highly efficient at capturing and retaining rainfall. The dense multi-layer structure of the Hawaiian rainforest absorbed water, allowing it to slowly percolate to the ground, and even slower to the underground system. The problem today, is that the Hawaiian rainforest is restricted to the Conservation Districts in the uplands. The Mānoa Valley Regional Park is nestled between the uplands and the midlands of the ahupua‘a, and is adjacent to the Mānoa Stream. It can be a “stepping stone” to begin reconnecting ecological systems along the stream. So, to extend the area of the upland rainforests down the valleys and to compensate for the urban degradation of our lower valleys and midlands, the solution will be the re-vegetating riparian buffers, re-foresting parts of open green patches, and urban-reforesting efforts within the urban environment.

The program will deconstruct the concrete channel currently present at the site and expand the existing swale, converting it into a wetland, to incorporate places of refuge for plants and animals and places of recreation and natural entertainment for people. The design will also incorporate riparian planting. Removing the channel concrete to expose the soil, for water infiltration. Expanding the width of the swale and allowing the water to enter the park, reducing storm water runoff, filtering the water, and retaining the water on-site instead of sending it away. Providing habitat for wildlife and recreation for the users.



## Actions for Stormwater Management and Water Quality Improvement

Criteria	Description
Concrete Removal	Exposing the stream bed, or using a porous engineered system can help to slow down channelized stream flow. It also provides habitats for wildlife.
Vegetation	A diversity of native riparian plants and others that have deep roots to control erosion and stabilize the bank edges. However, forest cover is the best use of land in a watershed and is superior to everything in terms of water storage, ground water recharge, runoff reduction, pollutant reduction, and habitat.
Edge Treatment	Gradual “softer” edges are ideal for water and land processes. Streams are constantly changing and reshaping themselves and their edges. They self regulate. Gradual edges also help to reduce erosion and slow down water flow.
Invasive Species	Removal and control of non-native understory plants along the riparian zone.
Stormwater Management	Design of the buffer and re-foresting the park should maximize the amount of time storm water stays on site and infiltrates. Construction of natural infrastructures such as infiltration basins can help to keep the water from becoming run-off, hindering erosion and sedimentation.

### Observation Area

The observation area replaces what was an open field with no designated sports use, unlike the rest of the park’s open fields. The northernmost open field is transformed into a constructed wetland that drains into the stream. The proposed footpaths intersecting it, providing the site’s users access to cross over to the stream or to the baseball fields. The observation area and constructed wetlands are directly adjacent to the parking lot and just south of the Mānoa Gardens Elderly Housing. At the edge of the constructed wetland, the observation area is inspired by the coupling of ‘Aka’aka and Nalehua’aka’aka from the legend. ‘Aka’aka represented by a terraced wall of stone that overlooks the Manoa Stream. Crimson-flowered Lehua trees will be planted on its “brow” to clarify the cultural identity of this particular space.

The observation area will be enjoyed by the elderly for its adjacency to the stream and to their homes. Prior to the proposal, the site for the observation area had a small amphitheater that was overgrown with native plants. While it offered plenty of shading, it did not have a purpose, nor did it point to a particular view. The amphitheater was probably used as an observation point to view the stream below, but because of the overgrown loulu and

hala, it was not functional. The observation area, clear of loulu and hala and replaced with rows of lehua trees will improve the aesthetic quality of this vantage point while not blocking any views to the stream. Users will be able to access the observation deck via the bridge from the east, through the existing parking lot to the north, and through the foot paths from the south and the rest of the park. The aesthetic quality of the constructed wetland will be a sight-to-see as the elderly, the children, and visitors take leisurely walks.

### Footpaths

Prior to the proposal, there was only one footpath in the entire park that dog walkers and walkers used to view the stream. The existing foot path was adjacent to the stream and linked to the existing parking lot to the north; it was a very short walk. In the proposal, a footpath that meanders along the periphery of the park and links narrative nodes will not only serve those who want to view the stream, or walk, but also function as a jogging and bicycle path. The footpaths will function as the narrative “flow” to the story of Kahalaopuna. Its materiality and curvilinear reflect the physical attributes that the landscape’s myth tells us.

The footpath is meant to begin at the community gardens to the west of the Manoa Gardens Elderly Housing. The community garden is nestled between the elementary school and the housing division. The path begins at that location as a symbol of the relationship of kupuna and keiki, and their roles to nurture and to learn. The path splits; one leads to the sports fields and the other leading through the northern constructed wetlands and into the observation area. The observation area is where the legend begins with terraced stone walls and plantings of lehua to commemorate ‘Aka’aka and Nalehua’aka’aka, who gave birth to wind and rain. The path turns south, following and meandering playfully alongside the adjacent Mānoa Stream. The path here is flanked by native trees and riparian planting. The path for this portion meanders to symbolize the flow of water and the flora flanking the path symbolize wind, which cannot be seen, but can be felt through the sounds and sways of the plants and the rushing of water. The footpath adjacent to the stream commemorate Kahaukani (wind) and Kauakuahine (rain).

At the southernmost tip of the park, the foot path turns northwest towards the southern constructed wetlands, which used to be another parking lot. The footpath splits; one

leading back into the sports fields and towards the northern parking lot, and the other towards the cultural garden to the north.

### *Cultural Garden*

The cultural garden is a large bioswales that is meant to collect and retain the water before it enters the stream. The garden is reminiscent of Sidwell Friends School's constructed wetland system. Stormwater will be redirected through curb cuts into the garden instead of into storm drains. The area will retain the the water until it infiltrates, evaporates, transpires or flows through site and into the wetlands, and finally the stream. The cultural garden will feature several of the plants that were mentioned in the legend such as hala, wiliwili, and auki, and also native upland forest trees in an effort to extend the upload forests down to the valley.




Figure 60: Planting for Manoa Valley District Park  
Source: By Author





**MANOA VALLEY REGIONAL PARK  
EXISTING CONDITIONS**

**LEGEND**

-  Flood risk area
-  Stream
-  Stormwater in/outlets



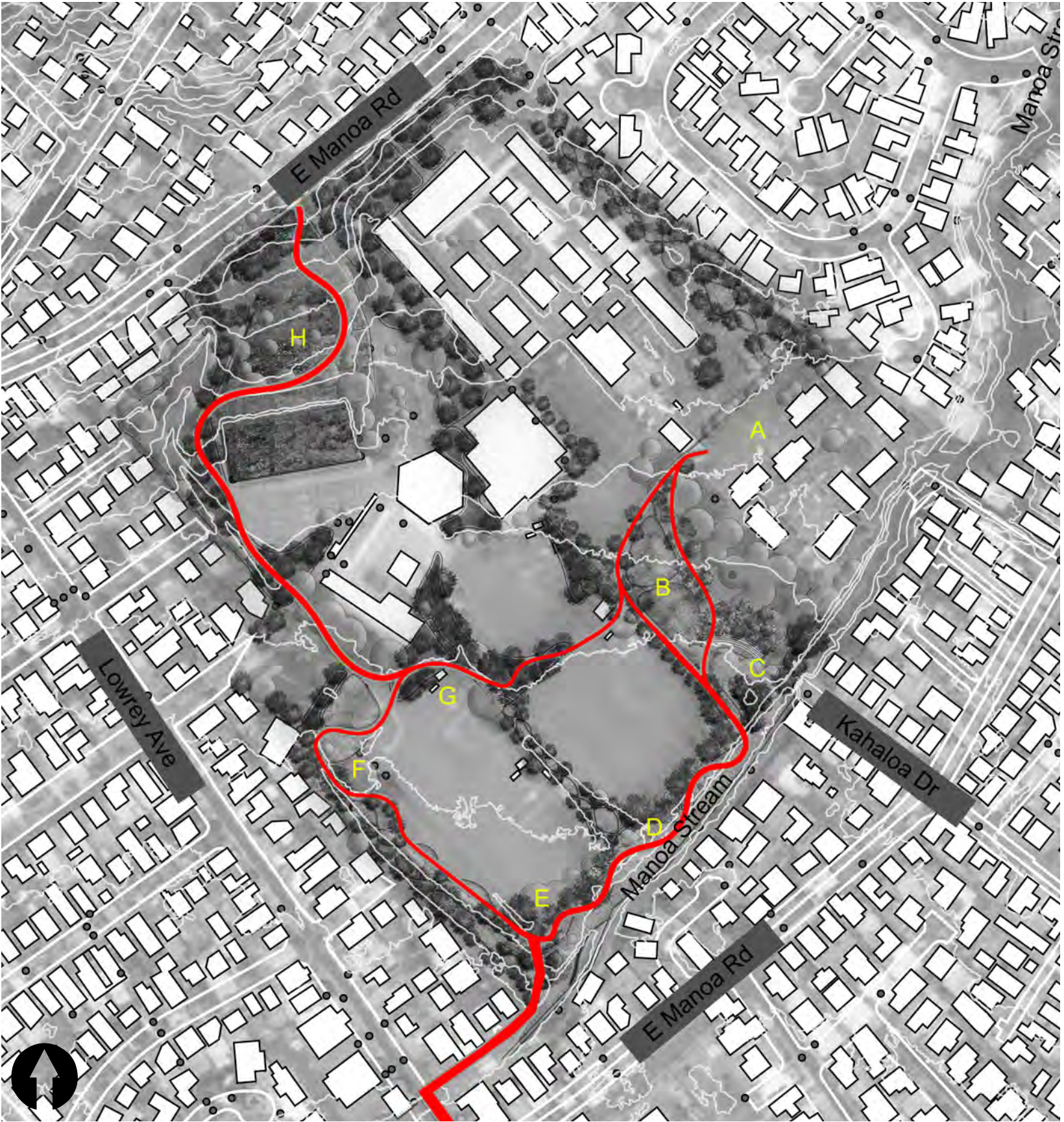


**MANOA VALLEY REGIONAL PARK  
MASTER PLAN**

**LEGEND**

A	Manoa Gardens Elderly Housing
B	Manoa Elementary School
C	Lehua Terrace
D	Stream Walk
E	Sports Field
F	Connection to the Ala Loa Trail
G	South storm water ponds
H	Cultural Gardens





**MANOA VALLEY CULTURAL PARK  
CULTURAL PART I**

**LEGEND**

A	Start of the foot path; begins between the kupuna and the keiki
B	Constructed wetlands
C	Lehua terrace to commemorate ‘Aka‘aka and Nalehua‘aka‘aka
D	Stream walk commemorating Kahaukani (wind) and Kauakuahine (rain)
E	Connects to the Ala Loa Trail
F	Storm water ponds to replace parking lots and increase pervious surface
G	A series of rain gardens
H	A cultural garden, doubling as a series of bioswales. Plants in this cultural garden corresponds with the legend of Kalohaupuna





**MANOA VALLEY CULTURAL PARK  
GREEN INFRASTRUCTURE**

**LEGEND**

A	A series of rain gardens
B	North constructed wetlands
C	Northern estuary and widening of the stream
D	A series of rain gardens
E	South storm water ponds
F	Southern estuary and widening of the stream



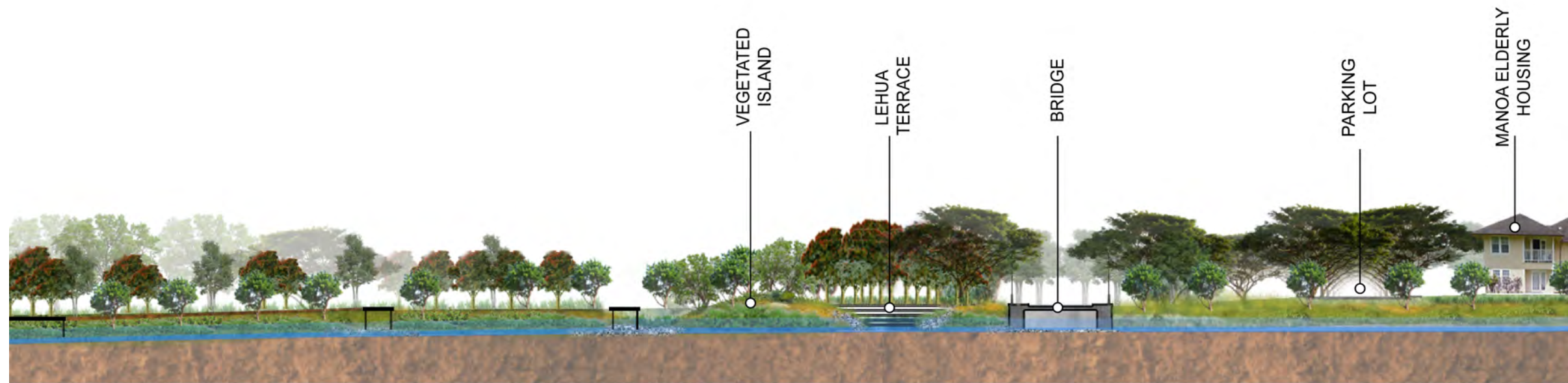


**MANOA VALLEY CULTURAL PARK  
PLANTING PLAN**

**LEGEND**

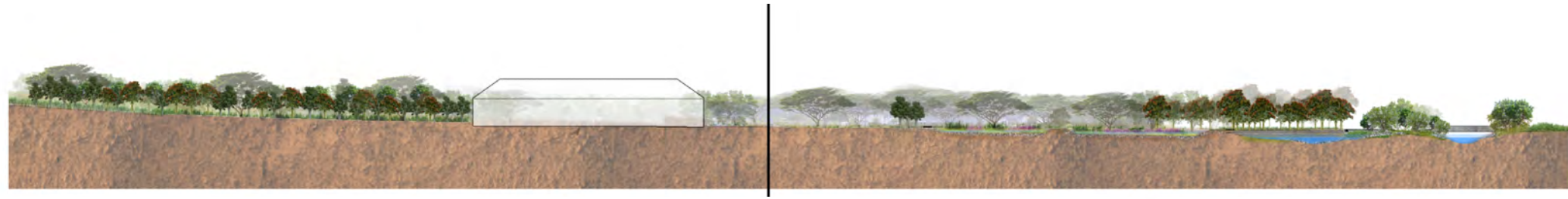
A	Lehua, pohinahina, aeae, kalo, and wetland grasses
B	‘Aki‘aki, pu‘uka‘a, ‘ahu‘awa, ‘akai‘akai, ‘ahu‘awa, kou, milo
C	Auki, lehua, maile, olena, kupukupu, hala, wiliwili
D	Milo, loulo, lehua, hala, wiliwili, naio, ‘iliahi, kou, kukui





MANOA VALLEY DISTRICT PARK SECTION AA





REFORSTED  
PORTION

MANOA ELEMENTARY  
SCHOOL



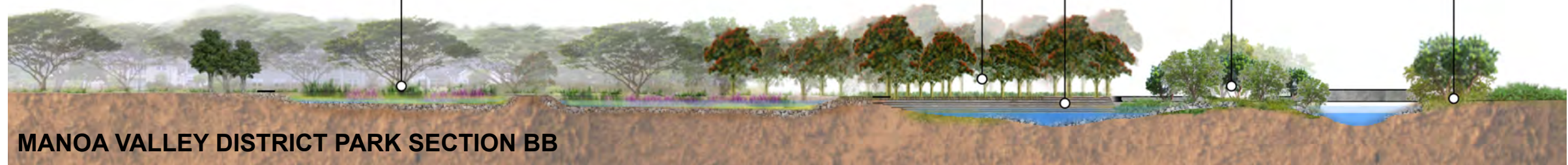
RECONSTRUCTED  
WETLANDS

LEHUA  
TERRACE

NORTH ESTUARY  
WIDENING OF  
STREAM

VEGETATED  
ISLAND

SOFTENING THE  
OPPOSITE EDGE OF  
MANOA STREAM



MANOA VALLEY DISTRICT PARK SECTION BB





VIEW OF THE SOUTH STORMWATER PONDS AT  
MANOA VALLEY REGIONAL PARK



## 6.4 KAIMUKI HIGH SCHOOL

Memory and Identity	Kalia and Pahoa have opposing characteristics in their names. The area was once used for agriculture and flower farming.
Social Attributes	Streamway, pedestrian connectivity, neighborhood connectivity, gardens
Physical Application	LIDs, stream restoration, vegetation, edge treatment

### **Memory and Identity: An area between two streams**

#### **Intertwining Kalia and Pahoa**

There are no legends and myths associated with the area nestled between the Kalia and Pahoa Stream. However, in the 19th century the area was a farm of King Kalākaua, where ostriches roamed wild over the mountain side. It later became the site of a carnation farm for funeral flowers. Today, the area is a mix of residences and a small business district along King Street. The two streams no longer exist because the Manoa and Pālolo stream merge before the area where Kalia and Pahoa used to be. Kalia means “waited for” and is a flower from a tree that was indigenous to the area. Pahoa refers to sharp rocks; which Hawaiian daggers are made of. A combination of Kalia’s gentleness with the roughness of the Pahoa Stream; these opposing characteristics and naming of these streams will drive the design. The area between the two streams were once used for agriculture and flower farming. Similar programs will be implemented within the adjacent sites.

### **Social Attributes: Community Connectivity & Education**

#### **Neighborhood Connectivity and Awareness for Sustainability**

Kaimuki High School is nestled between the stream and two different residential communities. It borders on Mō’ili’ili which is a community of transients and on Kaimuki, which is primarily single family home owners. There is a disconnect between neighborhoods and as such, the general landscape of the area contrasts with what it once was, a lush agricultural site nestled between two streams. The design proposal includes a walking path

along the stream which connects to the ala loa trail. This trail will be used by students and cyclists, and residents to go mauka or makai. A bridge will also connect both sides of the stream in the middle of the site.

Kaimuki High School will have gardens between the classroom buildings to call back to the memory of agriculture. Students and teachers will be exposed to sustainable systems and stormwater management systems. The intent is that the school will adapt these living practices in their curriculum to teach the keiki about stewardship and responsibility. Because the intent of the garden is to produce edible plants, the gardens will consist of vegetable varieties that are not native.

### **Physical Applications: Streamwalk & Cultivation Gardens**

#### ***A Pedestrian Streamwalk and School Food Gardens***

In the ancient ahupua‘a, the midlands of Waikīkī were used for agriculture and for settlements. In contrast with today’s urban cities, the ancient Hawaiians did not alter the landscape to a degree in which it would affect future generations. They utilized the stream systems for their agriculture and irrigation as we do, but they did very little to alter the landscape’s hydrology. Those that farmed the lands were placed under strict rules by the ali to respect the water and the land. Their infrastructure diverted water into their fields, but their fields functioned to clean the water, very much like natural and constructed wetlands. The problem today is that the area between the Kalia and Pahoa Streams is polluted and heavily sedimented because of the alterations done to the natural landscape and because of human carelessness.

The Kaimuki High School site can raise community awareness for the protection of the waterway, provide connectivity between neighborhoods, and teach and feed the students. The design proposal includes a path on the school side of the 100’ wide stream channel that sits on top of a constructed gabion terrace 8’ high from the bottom of the channel. The terracing is because of the varying degrees of water level this area of the stream experiences throughout the year. The terracing will mimic nature with a small bottom stream to handle annual flows and a series of gradually sloping embankments to handle flood flows when it rains. The terracing will afford areas for native riparian planting.

## Actions for Stormwater Management and Water Quality Improvement




Criteria	Description
Concrete Removal	Exposing the stream bed, or using a porous engineered system can help to slow down channelized stream flow. It also provides habitats for wildlife.
Vegetation	Majority of the channel is sedimented with invasive plant species. A diversity of native riparian plants and others that have deep roots to control erosion and stabilize the bank edges.
Edge Treatment	Remove sedimentation that covers more than half of the actual channel's width. Creating a tiered stream bed with rocks and compacted soil and then topping it with riparian planting that exceeds the 7' high flow that the Kaimuki area receives. Creating tiers; first tier is for overflow and for plants that can be submerged or partially submerged. Second tier will have plants that can survive partial submerged, third tier at 8' from the base of the channel is a walkway. The tiers will be curvilinear to create a meander within the linear channel.
Stormwater Management	Stormwater drains that lead to the channel will have a retention pool at a higher tier to clean the water before it hits the actual stream. Using rock gabions and sand to filter the water. Water will seep out of the gabion and into the stream. Cross-vane J-hooks





**KAIMUKI HIGH SCHOOL  
EXISTING CONDITIONS**

**LEGEND**

-  Flood risk area
-  Stream
-  Stormwater in/outlets





**KAIMUKI HIGH SCHOOL  
MASTER PLAN**

**LEGEND**

A	Restored stream
B	Stream walk
C	Permeable surface
D	Vegetable gardens
E	Fruit trees garden
F	Cultural trees
G	Track canopy
H	Mini dog park





**KAIMUKI HIGH SCHOOL  
CULTURAL PART I**

**LEGEND**

A	Leading to the Ala Loa trail crossing over the Kapiolani Blvd.
B	The meandering of the stream amidst the rigid confines of the channel commemorating the place names Kalia and Pahoa
C	Stream walk and a bridge connecting neighborhoods and offering a pedestrian path





**KAIMUKI HIGH SCHOOL  
GREEN INFRASTRUCTURE**

**LEGEND**

A	Implementation of anti-sedimentation strategies such as cross-vane and J-hooks
B	Meandering edge conditions to slow down the flow of water
C	Floating wetlands for the deeper part of the stream



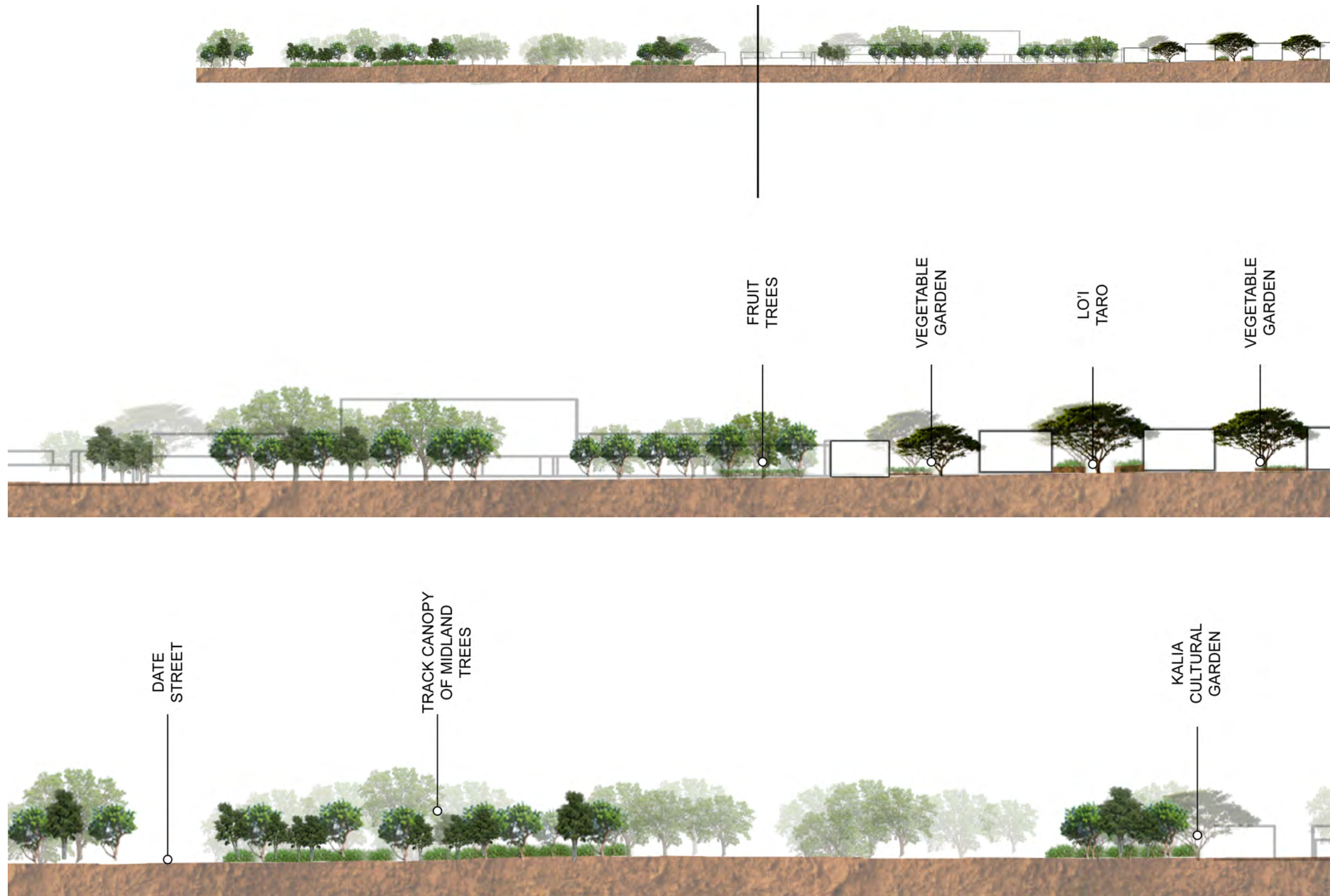


**KAIMUKI HIGH SCHOOL  
PLANTING PLAN**

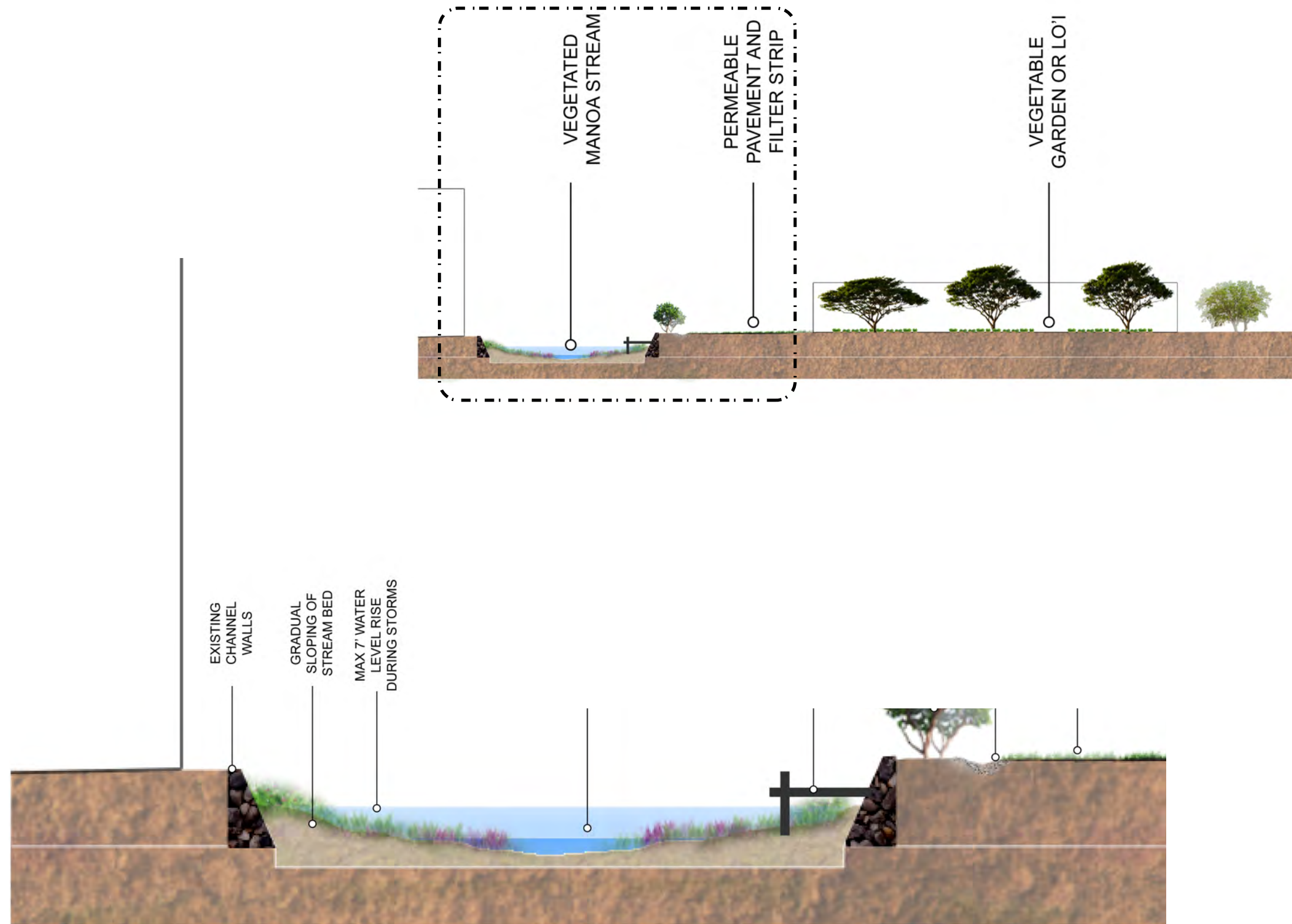
**LEGEND**

A	Permeable paving
B	Non-native vegetables
C	Taro lo'i
D	Fruit trees like banana, papaya, mango, and lychee
E	Kalia
F	Kou, kukui





**KAIMUKI HIGH SCHOOL SITE SECTION AA**



KAIMUKI HIGH SCHOOL SITE SECTION AA





VIEW TO THE VEGETABLE GARDENS AT KAIMUKI  
HIGH SCHOOL



## 6.5 KAPI‘OLANI REGIONAL PARK

Memory and Identity	The landscape speaks through stories of place and place names. The story of Waikolu describes the coasts of Waikīkī.
Social Attributes	Paki Place Connective Gardens, existing recreational park activities, the zoo, the natatorium, leisurely strolls through the constructed wetlands
Physical Application	LIDs, stream daylighting, rain gardens, constructed wetlands, reforestation, re-vegetation

### **Memory and Identity: Waikolu**

#### *Remembering the Coastal Wetlands*

Kapi‘olani Regional Park does not have many legends associated with it. Prior to being used as a public space, the area was a mix of swamp land and arid plain unsuitable for building. The park had many features throughout the years since its conception in the 1870s. Today, the park consists of open green space, lily ponds, the Honolulu Zoo and the Waikīkī Shell entertainment venue. Because the stream is being redirected and day lit to Kapi‘olani Park, the memory of Waikolu can be used to tell the story of the three streams that used to run through Waikīkī’s urban district. The three streams of Waikīkī: Kuekaunahi, ‘Apuakehau, and Piinaio are no longer present. Remnants of the stream by little storm water drainages along the mauka side of the Ala Wai Canal give an indication of where their flow might have been, but they empty into the Ala Wai and contribute to the pollution and sedimentation.

The design proposal is to run a small controlled stream from the eastern end of the Ala Wai all the way to the natatorium. The small stream will named the Ala Wai Stream. The small stream will divert occasionally to gardens and ponds along Paki Avenue, a curving strip of land that borders the north of Kapi‘olani Park and is already being used as public park space, community garden space, and playgrounds. The daylight stream will enter Kapi‘olani Park and go through a series of constructed wetlands that represent Waikolu.

Waikolu is made up of Kuekaunahi, ‘Apuakehau, and Piinaio, each with their own characteristics and meanings. The meaning of Piinaio has been lost, but it was known for its

fishponds, loi kalo, and the area had brackish water. The stream didn't empty directly into the ocean. Instead it was a delta-like marshy buffer area that slowly filtered the water out. 'Apuakehau means "basket of dew" and it was known for its vast quantities of palm trees that were used to weave baskets. 'Apuakehau was a place of healing. Kue translates into fish hook, but the actual meaning of Kuekaunahi is lost.

These characteristics of Waikolu translate into the design of the three areas of the Kapi'olani Constructed Wetlands. The first area will be dedicated to Piinaio, which was a buffer area that slowly filtered the water and had many agricultural cells for fishponds and kalo. The design of the first area will be a multi-celled wetland that takes the concept of a loi kalo in taking in the water, and making sure it empties cleaner than it came in, while giving life to the plants. The water will then filter out into the second area, which is dedicated to 'Apuakehau, a place of healing. In the 'Apuakehau area, the design will include cavities where an array of native plants from mauka to makai can grow in different environments. The idea for this area is to see which of the ancient native plants can still grow and perpetuate in the present day conditions of Kapi'olani Park. The third area is closest to the slopes of Laē'ahi. This area is dedicated to the Kuekaunahi Stream, where the physical design of the landscape will be inspired from its name and its function will be to "hook" people in using the forested area for recreation.

### **Social Attributes: Daylit Streams, Connective Gardens, and Constructed Wetlands**

#### **A Leisurely Stroll**

The Kapi'olani Park design proposal will have several social attributes. The park is connected to the ala loa trail system. The trail from Kapi'olani will serve cyclists, joggers, and pedestrians that already make use of the Ala Wai corridor as an exercise route. The entire design proposal consists of three interventions. Firstly, the ala loa trail will run alongside the daylit stream from the Ala Wai Canal's Kapahulu Avenue exit, following the curvature of Paki Place, and enter the park on the junction of Paki Avenue and Monsarrat Avenue.

Secondly, Paki Avenue will host a variety of rain gardens that connect to the daylit stream via culverts under the existing street. The existing Paki Avenue is one of the greenest streets in Oahu. Towering trees and a green median make it a shady and cool corridor that many residents and tourists enjoy walking, cycling, and driving through. Paki Avenue is also home to several open parks, playgrounds, and community gardens. The use of this strip of

land is agricultural and recreational so its transformation into rain gardens and other LID strategies for water remediation instead of solely recreation will benefit the overall “greenness” that the Paki Avenue corridor is known for. At the same time, residents, students, and visitors will be able to go through the new Paki Place Connective Gardens and be educated on the effects of stormwater remediation through informative signage.

Thirdly, the park itself will be home to the Kapi‘olani Park Constructed Wetlands. It is a huge park that can be shared between ecological services and recreational services. The park will retain most of its original recreational functions, including the entertainment shell, tennis courts, soccer fields, softball fields, and baseball fields. However, the campgrounds and the open fields to the east will be used for the constructed wetlands. The constructed wetlands will receive the day-lit Ala Wai Stream and will serve as the final remediation system before the Ala Wai’s waters enter the ocean. Within the designated wetland areas, a series of paths that are connected to the ala loa can be used for leisurely walks through the Piinaio Wetland and the ‘Apuakehau Palette. The Kuekaunahi Grounds of the park will have areas for picnics and open field lawns for a variety of activities.

### **Physical Applications: Closing the Loop**

In the ancient ahupua‘a, the coastal marshes in Waikīkī were crucial to the environmental health of the watershed because it served as water storage and infiltration system while naturally filtering nutrients and pollution originating from the uplands. It also protected both human and wildlife communities from ocean storms by absorbing incoming wave energy. The coastal marshes served as estuaries or as breeding grounds for wildlife. The problem is that the Ala Wai Watershed does not have the benefits of a coastal marsh. Therefore, storm-water runoff goes directly into the receiving body of water—the ocean—without being relieved of soil, sedimentation, nutrients, and pollutants. The solution will be a train of constructed wetlands and gardens coupled with the daylighting of the stream through its new exit along Kapahulu Avenue. These solutions are the missing pieces in the ideal closed-loop system wherein run-off infiltrates to the ground water supply, and surface water quality improves before being released into the oceans. The constructed wetlands should over-compensate and be adequate not just for stormwater run off, but also for wastewater, in the event that sewage once again pollutes the Ala Wai Watershed’s waters.

## Actions for Stormwater Management and Water Quality Improvement

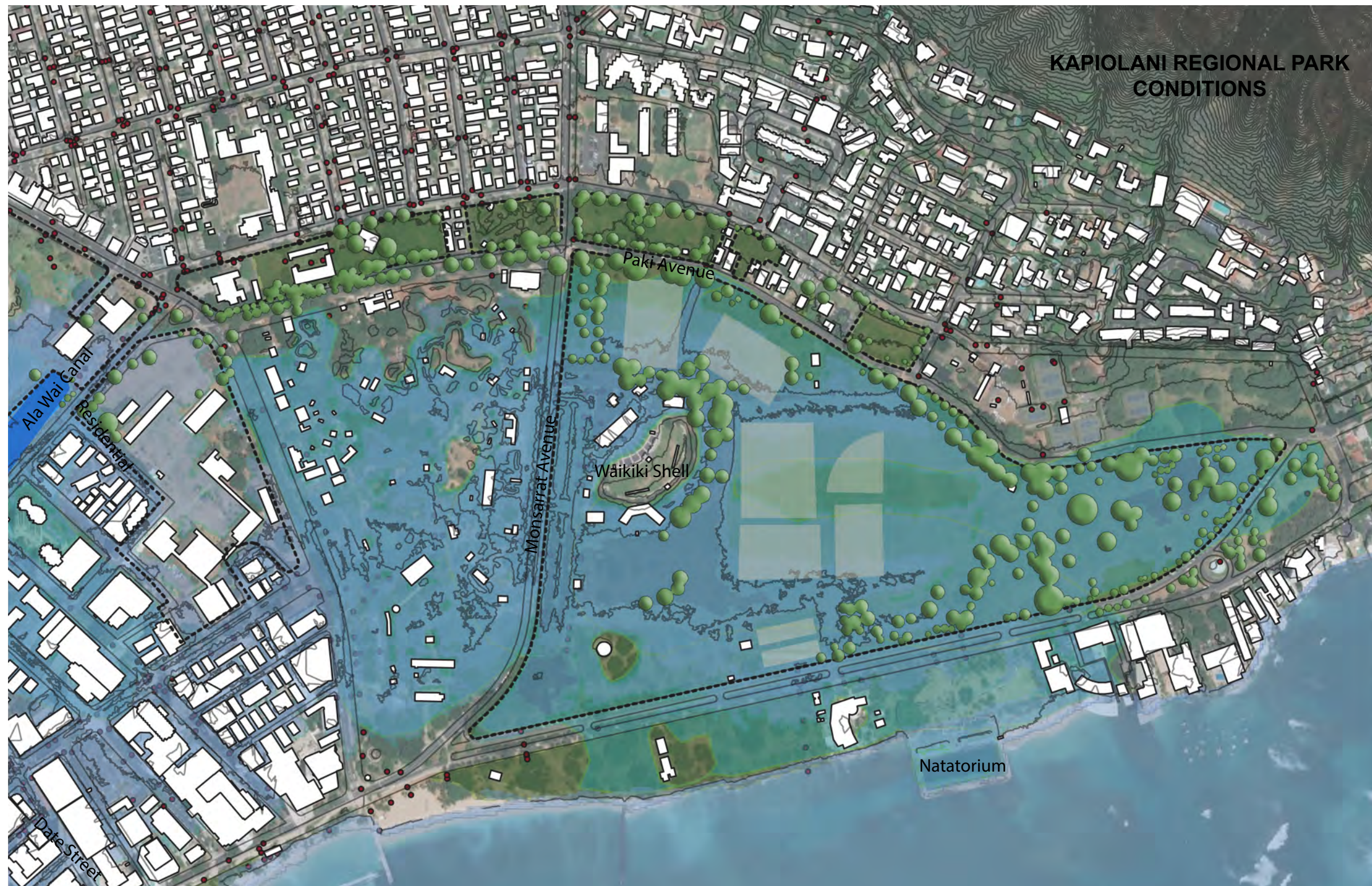
Criteria	Description
Daylighting	The stream will be daylight along Paki Avenue. It will be channeled into culverts when it has to cross the street. The stream will feed into gardens and ponds that are along Paki Avenue. Water will either be retained in those gardens and ponds or be redirected back into the daylight stream. The stream will enter the Kapi‘olani Park constructed wetlands and go through its final remediation.
Multiple Areas and Cells	The Kapi‘olani Constructed Wetlands are divided into three areas. The first area are the cells for plants that are solely for cleaning the water and retaining sediment. The second area will be a “palette” of carved out “diamond” shaped cavities and mounds to create a mixture of water ponds, wetlands, seasonal pools, and dry cavities, which are fed by rains and groundwater and the water from the constructed wetland. The goal is to create patches of vegetation that will naturally respond to the environmental qualities of Kapi‘olani Park.
Stormwater Management	The third area of the park which is the farthest and closest to Laē‘ahi will be reforested and resloped, but not function as a constructed wetland. This area will be used to collect the water from the steep slopes of Laē‘ahi and channel it into the two wetland areas. Design of the wetland system will be to slow down the water flow, retain storm water and let it infiltrate the soil to maximize the time it stays in the area for a successful wetland/marsh.
Forested Park	The third area of Kapi‘olani will be used as a recreational area for picnickers and campers, and other leisurely activities. Trees will be planted, groundcover for retaining water.

Figure 61: Native plants for Kapi‘olani Regional Park  
Source: By Author



Figure 62: Native plants for constructed wetlands water remediation.  
Source: By Author



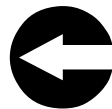




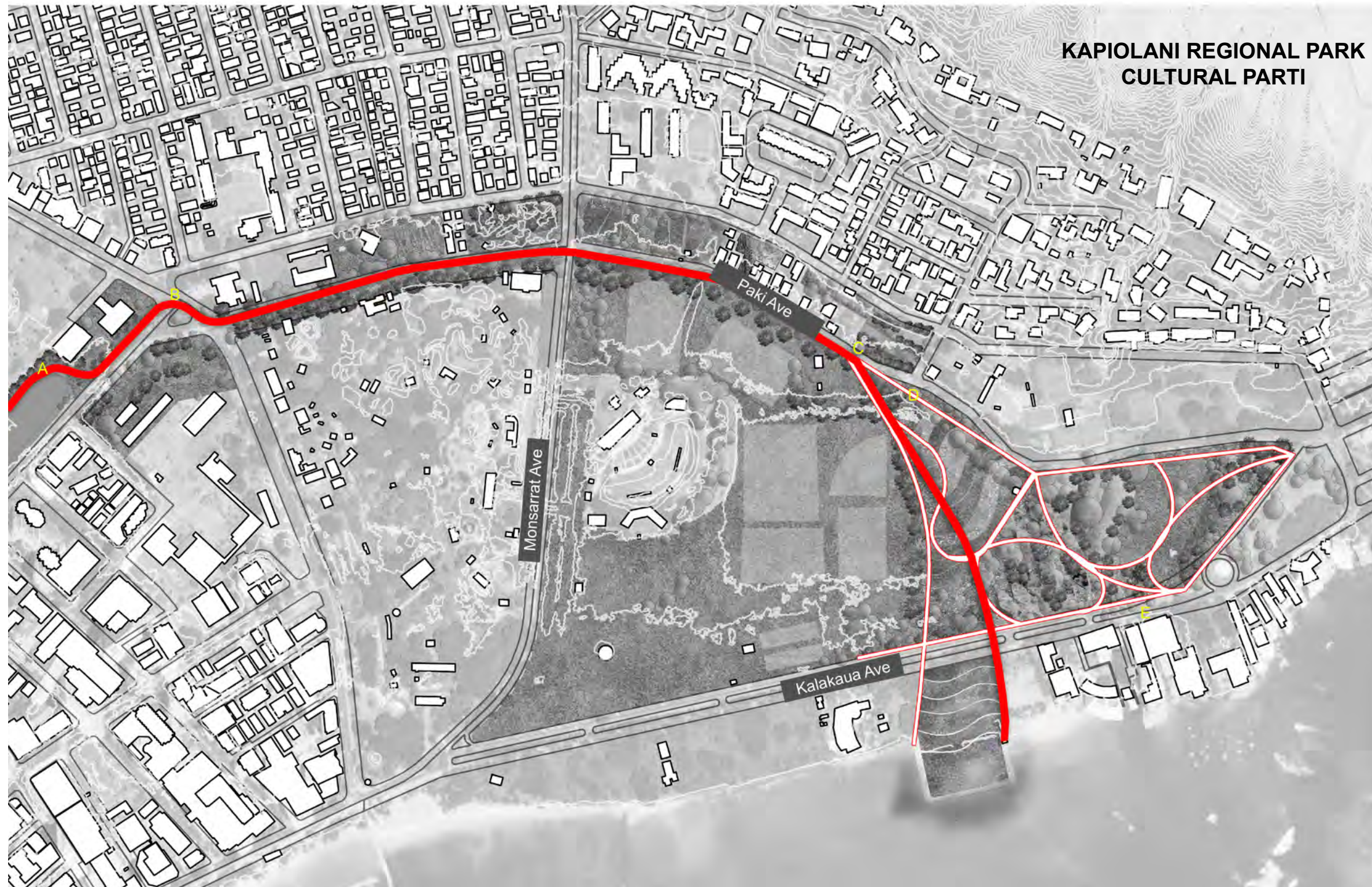


## KAPIOLANI REGIONAL PARK MASTER PLAN

- (A) Ala Loa trail systems; (B) daylighted Ala Wai stream; (C) Jefferson Elementary School constructed wetlands; (D) Ala Wai stream crossing through culverts; (E) rain gardens; (F) cultural gardens; (G) storm water ponds; (H) Ala Wai stream entering Kapiolani Park; (I) community gardens; (J) terracing constructed wetlands; (K) Pi'inaio wetlands; (L) Kuekaunahi grounds; (M) existing recreational area; (N) 'Apuahehau Palette; (O) continuation of Pi'inaio wetlands; (P) old Nanatorium; (Q) Ala Loa trail system terminus; (R) existing sports field







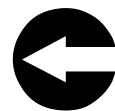
(A) daylighted Ala Wai stream to commemorate the continuation of Manoa stream; (B) the daylighted stream crosses the streets through underground culverts; (C) Ala Loa and Ala Wai stream enters the constructed wetlands; (D) pedestrian walk path to explore the new cultural landscapes







(A) Niu and wetland vegetations; (B) Pohinahina, aeae, ‘ahu‘awa, awa, ape, hala, kalo, ukiuki, ohe; (C) existing vegetaion plus kou and mahauhele; (D) aeae, akiaki, akulikuli, wala, ukiuki, pili, ilie‘e, ‘ahu‘awa; (E) awa, ape, aeae, akulikuli, akiaki, ukiuki, pili, kawelu emoloa, pohuehue, akoko, ihiihi, kalo; (F) different types of plants; (G) kukui, koa, maile, milo; (H) awa, ape, aeae, akulikuli, akiaki, ukiuki, pili, kawelu emoloa, pohuehue, akoko, ihiihi, kalo







VIEW OF THE STREAM BEING DAYLIT AT THE  
KAPAHULU END F THE ALA WAY CANAL



VIEW TO THE TERRACE WETLANDS ADJACENT TO THE ENTRANCE TO THE  
KAPIOLANI REGIONAL PARK CONSTRUCTED WETLANDS







AERIAL VIEW OF THE TERMINUS AT THE OLD WAR  
NATATORIUM



## **VII CONCLUSION**

## 7.1 OVERVIEW

A landscape's inherent characteristics—physical attributes, human activity, collective memory, and enduring symbols and lasting meanings—give it an identity. In Hawaii, water sculpts the landscape. The landscape sculpts culture and society. And the Hawaiians truly personified the landscape. They believed everything in the landscape belonged to the gods. God's land was sacred and treated with respect. Reverence for the natural landscape created a filial relationship between the natural environment and the human society. They structured their society to be in-sync with their natural environment because they understood that dependency on their surroundings.

With the arrival of Westerners in the late 1700s, the identity of the Hawaiian landscape changed. The arrival of foreigners introduced a false dichotomy between the built and natural environment and erased the long-standing relationship between the Hawaiians and their environment. The foreigners devoured the landscape, and the more they devoured, the farther culture and society drifted away from the natural environment. Today, the people of Hawaii sculpts the landscape themselves, cutting the land into pieces of marketable goods and controlling the water through hydromodification.

The landscape shifted from being wholly *ko mau akua 'āina* to fragmented pieces of real property. It is important to bridge the disconnect between culture and nature by addressing the components of a landscape's identity: the physical, the social, and the symbolic. This dissertation addressed how the inherent characteristics of the ancient *ahupua'a* informed design interventions for Hawai'i's current water infrastructure. The design proposals strengthened the landscape identity by engaging the environment, engaging the users, and engaging the symbols and myths in the landscape.

## 7.2 UNIQUE ASPECTS OF THIS PROJECT

There are different ways and different disciplines that address the adverse effects of hydromodification. It would take a multidisciplinary team and many phases spanning years to fully address the problems within the Ala Wai Watershed. Most solutions don't focus on place-based design. Therefore, this project contributes to the greater discourse by offering design solutions that explore the role of landscape, water, and identity in mitigating the adverse physical, social, and symbolic effects of hydromodification in the Ala Wai Watershed. The project proposed design interventions at the extent of the conceptual.

The proposed design interventions approached the problems through expressing the importance of landscape identity. First, it showed the importance of water in reconnecting mauka to makai while incorporating human services in a way that narrates the culture, the myths, and the symbols of landscape into the overall design. The project attempted to re-establish long-term sustainability in the future Ala Wai Watershed through landscape identity and by deriving concepts from the ahupua'a model of watershed management.

All of the design interventions are based on Hawaiian myths and legends about the place. The social attributes of each site can be traced to the ancient society's use of the place coupled with modern use, and the interventions addressed hydromodification through the use of soft, green infrastructure that mimics the ahupua'a as opposed to engineering-focused infrastructure solutions.

The site selection of parks adjacent to the Mānoa Stream showed the role of open spaces in addressing run-off and the role of parks in the initial filtration of water before it enters into the stream. The dissertation explored not only the potential of parks in addressing recreational services and ecological services, but also showed the effects small scale interventions when compounded and implemented throughout the entire watershed.

Some of the many design concepts incorporated in the design interventions are as follows:

- Water that acts as the central organizing structure of the site.
- Using the memory of water to create an identity for a waterless landscape.
- Natural infrastructure acting as social and cultural stimuli within the urban setting.



- Design logic derived from the landscape's narrative.
- Varied landscape experiences in each site.
- Programmatic elements alongside with natural infrastructure within the urban setting that tie in to the landscape identity of the place.
- Reverting to natural infrastructure as flood control measure as opposed to engineering measures.
- Incorporating keiki to foster awareness about watershed issues and opportunities for environmental and ecological education.
- Linking humans and their environment, fostering a community relationship to water, through stories.
- Wetlands doubling as recreational waterfront area.
- Reconnect the population and streams by maximizing layers of experience.
- Connecting fragmented sites throughout the landscape that are linked through the water.
- Flood mitigation by mimicking nature's stream bed: a small bottom stream to handle annual flows and a series of gradually sloping embankments for flexibility and soil stabilization.
- Dechannelizing the stream to allow vegetation to grow, providing wildlife habitat, and controlling erosion.
- Planting native vegetation wherever possible to foster permeable surfaces.
- Replacing park turf with native riparian trees, shrubs, and ground cover species.

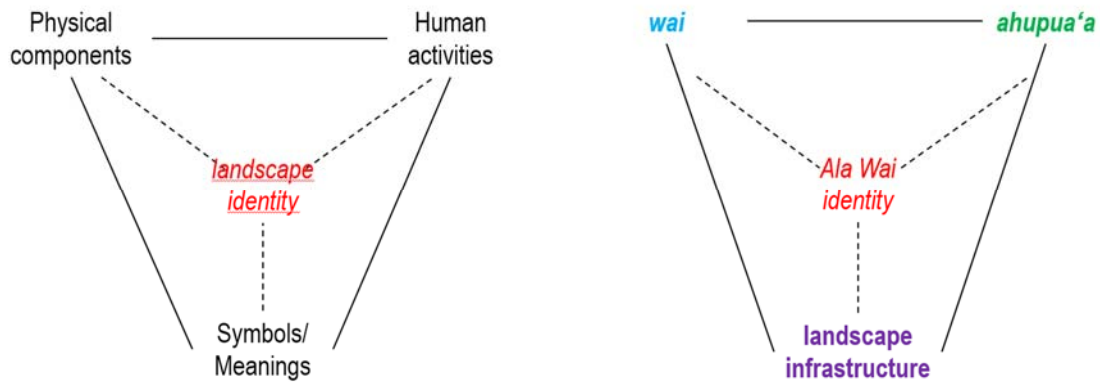


Figure 63: Ala Wai landscape identity  
Source:

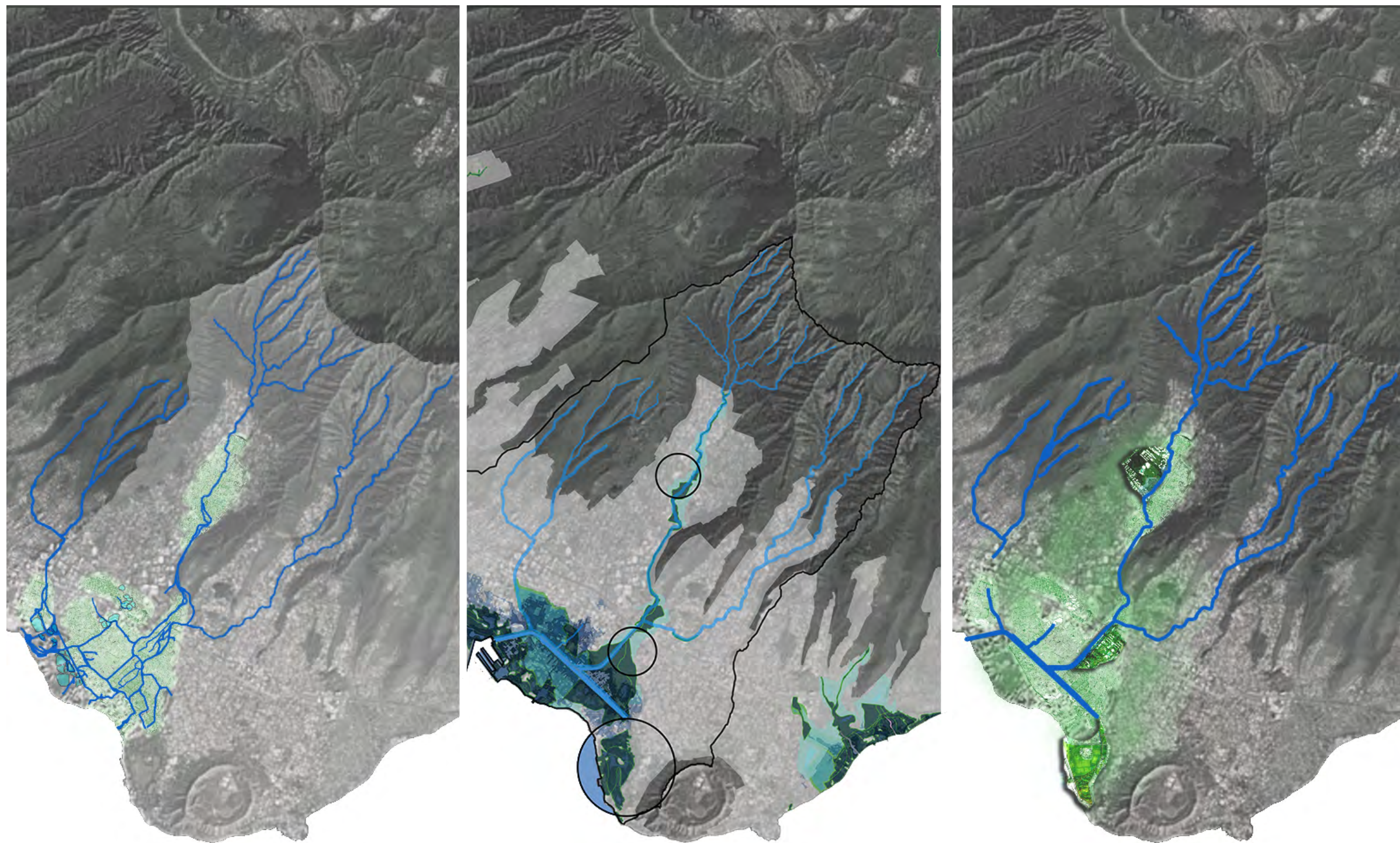
Problem	Solution	Catalyst for Identity
There is a physical disconnect between the urban and natural environment.	Strengthen the identity of the landscape.	The water is a <i>physical attribute</i> of the landscape that runs from mauka to makai as a part throughout the landscape, connecting the physical and cultural aspects between the urban and natural environment.
Water is the backbone of Hawai'i's urban and natural environment and good water quality depends on a closed-loop system.	Embed natural elements into the urban environment to reflect commensality and raise an awareness for the importance of water.	The ahupua'a evolved from <i>human activity</i> within the landscape. It encompasses stewardship, preservation, restoration, and consumption of the ecosystem services within a closed-loop system. It reflects awareness and commensality between the natural and the human environment.
The Ala Wai Watershed's urban framework is vulnerable to disasters because of "hard" infrastructure.	Mitigate the effects of hydromodification by using green infrastructure.	The ancient Hawaiians derived <i>meanings and symbols</i> from the landscape to work in sync with it. Their infrastructure did little to alter the landscape and in fact improved the quality of water as it flowed down the ahupua 'a.

## 7.3 RESULTS

The old Waikīkī ahupua‘a was a healthy watershed that prospered because the ancient Hawaiians had a filial relationship with their landscape. The Ala Wai Watershed is the unhealthy successor because of the cultural disconnect with the landscape. The watershed serves as a home to a big population, albeit a size that the watershed cannot independently support. The problem is that the watershed is degraded to the point that the ecosystem services it provides are limited to inferior storm water drainage and at-health-risk recreation. The water network does not provide potable water, food resource, and wildlife habitat among other services that a healthy watershed should be providing. The design solution presented succeeds the unhealthy Ala Wai Watershed because it amalgamates the memory of the old Waikīkī ahupua‘a into the existing fabric physically, socially, and symbolically.

Below is a pictorial comparison of the ancient Waikīkī ahupua‘a and of the current Ala Wai Watershed and the proposal for a re-branded, sustainable Ala Wai Watershed.





A COMPARISON OF ANCIENT, CURRENT, AND FUTURE ALA WAI WATERSHED

## 7.4 EXPANSION OF RESEARCH

The project focused on reincorporating cultural values into a conceptual design through strengthening the landscape's identity. To further this project, the next step would be to research the hydrological and geological aspects of the watershed with sea-level rise in mind to clarify and adjust the designed interventions. Another step would be to delve into the engineering discourse to further strengthen the conceptual green infrastructures that were proposed with technical knowledge. The last step would be to understand the economic effects of the proposed changes. The success of many precedent studies of stream remediation within the urban fabric leads me to believe that a study of the economic feasibility and projected gains from the design proposal could inspire professionals to consider using "soft" infrastructure instead of the traditional "hard" infrastructure. The expansion of the research into the three areas would create an argument to the plausibility of the conceptual designs to become actual, solid, multi-disciplinary solutions for the Ala Wai



## VIII BIBLIOGRAPHY

## Bibliography

- Acson, Veneeta. *Waikiki: Nine Walks through Time*. Norfolk Island, Australia: Island Heritage, 1983. Print.
- Ahupua‘a Agricultural Association of Hawaii. *Ahupua‘a*. Digital image. *Kauai University Web Log*. N.p., 18 Jan. 2013. Web. 10 Dec. 2016.
- AlaWaiChallenge.org. "Resources." *Ala Wai Student Design Challenge*. N.p., n.d. Web. 2 Dec. 2016.
- Andropogon Associates, Ltd. *Sidwell Friends Middle School Plan*. Digital image. *Landscape Performance*. N.p., n.d. Web. 10 Dec. 2016.
- Army Corps of Engineers. *Ala Wai Canal Project, Oahu, Hawaii Feasibility Study with Integrated Environmental Impact Statement*. By United States Army Corps of Engineers (USACE). N.p.: n.p., 2015. Print.
- Baker, Ray Jerome. *Taro Fields*. Digital image. *Ray Jerome Baker Collection*. N.p., n.d. Web. 10 Dec. 2016.
- Bannerman, Susan, and British Columbia. Ministry of Forests. Research Branch. *Biodiversity and Interior Habitats : The Need to Minimize Edge Effects. Part 6 of 7 Part 6 of 7*. Victoria, B.C.: Ministry of Forests, Research Program, 1998. Print.
- Barreire, Dorothy B., Mary Kawena Pukui, and Samuel Manaiakalani Kamakau. *Tales and Traditions of the People of Old / Nā Mo‘olelo O Ka Po‘e Kahiko*. Honolulu: Bishop Museum, 1991. Print.
- Barss, Martha. *Watershed Cross Section Diagram*. Digital image. *RPCS.org*. N.p., 8 Sept. 2012. Web. 10 Dec. 2016.
- BBC. *Rainforest Water and Nutrient Cycles*. Digital image. *Bitesize*. N.p., n.d. Web. 10 Dec. 2016.
- Beckwith, Martha Warren,. *The Kumulipo, a Hawaiian Creation Chant*. [Chicago: U of Chicago, 1951. Print.
- Bell, Simon. *Elements of Visual Design in the Landscape*. London: E & FN Spon, 1996. Print.
- Bloom, Arthur. "Stream Erosion and Landscape Development." *Water Encyclopedia: Science and Issues*. N.p., n.d. Web. 16 Dec. 2016.
- Board of Water Supply. "Oahu's Water History." *Board of Water Supply*. N.p., n.d. Web. 16 Dec. 2016.

- Board of Water Supply. *Water for Life The History and Future of Water on O'ahu*. Honolulu, HI: Board of Water Supply, n.d. Web. 16 Dec. 2016.
- Board of Water Supply. *Water Master Plan*. Honolulu, 2016. Accessed December 10, 2016. <http://www.boardofwatersupply.com/bws/media/files/water-master-plan-public-draft-2016-07.pdf>.
- Booth, Norman K. *Basic Elements of Landscape Architectural Design*. New York: Elsevier, 1983. Print.
- Breen, Ann. *Waterfronts: Cities Reclaim Their Edge*. New York: McGraw-Hill, 1994. Print.
- A Brief History of Water Rights in Hawai'i, with Earth Justice Attorney Isaac Moriwake*. Prod. Noni Films. Perf. Isaac Moriwake. *Youtube*. N.p., 29 Apr. 2009. Web. 16 Dec. 2016.
- Bruttomesso, Rinio. *The Oriental Dimension of the Waterfront : Waterfront Reorganisation in Singapore, Jakarta, Kuala Lumpur, Bangkok, Saigon and Sydney*. Venezia: Marsilio, 1997. Print.
- Burkhead, Noel M. "Extinction Rates in North American Freshwater Fishes, 1900-2010." *BioScience* 62.9 (2012): 798-808. Web.
- Cappiella, Karen, Thomas R. Schueler, and Tiffany Wright. *Urban Watershed Forestry Manual : Part 1/ Methods for Increasing Forest Cover in a Watershed*. Newtown Square, PA: United States Department of Agriculture, 2005. Print.
- Carbon Neutral. *Yarra Yarra Biodiversity Corridor*. Digital image. *Carbon Neutral*. N.p., n.d. Web. 10 Dec. 2016.
- Carlisle, Stephanie, and Nicholas Pevzner. "Introduction: Rethinking Infrastructure." *Scenario Journal*. N.p., 24 Oct. 2015. Web. 11 Nov. 2016.
- CASQA. *Introduction to Hydromodification by the California Stormwater Quality Association*. N.p.: Sacramento Stormwater Quality Partnership, 2009. Web. 16 Dec. 2016.
- City of Wixom, Michigan. "Watershed." *Wixom, MI : Watershed*. City of Wixom, n.d. Web. 19 Jan. 2017. <<http://www.wixomgov.org/government/public-works/watershed>>.
- Clarke, Robin. *Water: The International Crisis*. Cambridge, MA: MIT, 1993. Print.
- Conceptual Plan*. Feb. 2015. Honolulu. *Ala Wai Canal Flushing System and Ala Wai Golf Course Detention System*. By Mitsunaga & Associates, Inc. Honolulu: DLNR, 2015. N. pag. Print.
- Dekneef, Matthew. "Hawaiians Have More than 200 Words for Rain." *Hawaii Magazine*. N.p., 04 Mar. 2016. Web. 14 Dec. 2016.

- Descloitres, Jacques. Flooding of the Nile. Digital image. *Earth Observatory*. N.p., 11 Aug. 2003. Web. 10 Dec. 2016.
- Division of Forestry and Wildlife, Department of Land and Natural Resources (DLNR). "Land Management." *West Maui Mountains Watershed Partnership*. N.p., n.d. Web. 12 Dec. 2016.
- DLNR. *Hawai'i Statewide Comprehensive Outdoor Recreation Plan 2015 Update*. Rep. Ed. Department of Land and Natural Resources. N.p.: National Park Service, 2015. Print.
- Dramstad, Wenche E., James D. Olson, and Richard T. T. Forman. *Landscape Ecology Principles in Landscape Architecture and Land-use Planning*. Cambridge, Mass.: Harvard U Graduate School of Design, 1996. Print.
- Dunford, Betty, and Aimee A. Kudlak. *The Hawaiians of Old*. Honolulu, HI: Best, 1980. Print.
- Dunford, Betty, Lilinoe Andrews, Miki'ala Ayau, Liana I. Honda, and Julie Stewart, Williams. *The Hawaiians of Old*. Honolulu, Hawaii: Bess, 2002. Print.
- Ejiri, Masakazu. *The Development of Waikiki, 1900-1949 : The Formative Period of an American Resort Paradise*. Thesis. University of Hawaii, 1996. Ann Arbor, Mich.: UMI Dissertation Services, 1998. Print.
- Elmqvist, Thomas, ed. *Urbanization, Biodiversity and Ecosystem Services : Challenges and Opportunities : A Global Assessment*. Dordrecht: Springer, 2013. Web. 16 Dec. 2016.
- Encyclopædia Britannica. "Orographic Precipitation." *Encyclopædia Britannica*. N.p., 20 July 1998. Web. 16 Dec. 2016.
- Encyclopedia Britannica. *Orographic Lift*. Digital image. *Britannica*. N.p., 20 July 1998. Web. 10 Dec. 2016.
- Enos, Solomon. *Papa and Wakea*. Digital image. *Pinterest*. N.p., n.d. Web. 10 Dec. 2016.
- Evenhuis, N. L., J. Michael Fitzsimmons, and Symposium on the Biology of Hawaiian Streams and Estuaries. "The Hawaiian Ahupua'a Land Use System: Its Biological Resource Zones and the Challenge for Silvicultural Restoration." *Biology of Hawaiian Streams and Estuaries : Proceedings of the Symposium on the Biology of Hawaiian Streams and Estuaries : Hilo, Hawai'i, 26-27 April 2005*. Honolulu: Bishop Museum, 2007. N. pag. Print.
- Feeser, Andrea, and Gaye Chan. *Waikiki: A History of Forgetting and Remembering*. Honolulu: U of Hawai'i, 2006. Print.

- Ferguson, Ivy. *How Wetlands Work*. Digital image. *Environment Tobago*. N.p., n.d. Web. 10 Dec. 2016.
- Ffolliott, Peter F., Daniel G. Neary, Rocky Mountain Research Station (Fort Collins, Colo.), and University of Arizona. School of Renewable Natural Resources. *USDA Forest Service Proceedings RMRS-P-13*. 2000. Land Stewardship in the 21st Century : The Contributions of Watershed Management : Conference Proceedings, Tucson, Arizona, March 13-16, 2000. N.p., n.d. Web. 16 Dec. 2016.
- Fitzgerald, Duncan, and Joseph Melanson. *Breaching the Beach*. Digital image. *Oceanus Magazine*. N.p., n.d. Web. 10 Dec. 2016.
- Food and Agriculture Organization of the United Nations (FAO). *The New Generation of Watershed Management Programmes and Projects: A Resource Book for Practitioners and Local Decision-makers Based on the Findings and Recommendations of an FAO Review*. Rome: Food and Agriculture Organization of the United Nations, 2006. Print.
- Forest Service National Earth Sciences Conference, Pacific Northwest Research Station (Portland, Or.), and Michael J. Furniss. *Advancing the Fundamental Sciences : Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004*. Ed. Catherine Faye Clifton, Kathryn L. Ronnenberg, and Stephen P. Glasser. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station, 2007. Web.
- Gartner, Todd, ed. *Natural Infrastructure Investing in Forested Landscapes for Source Water Protection in the United States*. Vol. 2. N.p.: n.p., 2013. Web. 16 Dec. 2016.
- Genesis*. *King James Bible*. Nashville, TN: Holman Bible, 1973. Print.
- Greider, Thomas, and Lorraine Garkovitch. "Landscapes: The Social Construction of Nature and the Environment." *Rural Sociology* Spring 1994 59.1 (n.d.): 1-24. Web. Qw Dec. 2016.
- Grinin, Leonid. "The Urbanization and Political Development of the World System: A Comparative Quantitative Analysis." *History & Mathematics: Historical Dynamics and Development of Complex Societies*. By Andrey Korotayev. Ed. Peter Turchin. Moscow: KomKniga/URSS, 2006. 115-53. Print.
- "Habitat Alteration." *Encyclopedia.com*. N.p., 2009. Web. 16 Dec. 2016.
- Hammer, Donald A. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural*. Chelsea, MI: Lewis, 1989. Print.



- Harms, Hans. *Changes on the Waterfront - Transforming Harbor Areas: Comparison and Evaluation of Waterfront Developments in Two Contexts: San Francisco Bay Area and Hamburg, Germany*. Working paper. Berkeley: U of California, Berkeley, 2007. Print.
- Hawaii State Archives. *Kapi'olani Park Racetrack*. Digital image. *The Honolulu Advertiser*. N.p., 15 Dec. 2002. Web. 10 Dec. 2016.
- Hawkins, Richard A. "The Impact of Sugar Cane Cultivation on the Economy and Society of Hawaii, 1835-1900." *Illes I Imperis* 9 (2006): 59-77. Web. 16 Dec. 2016.
- Henshaw, John, and James G. Lewis. "The Lessons of History: Making a Case for a National Forest in Hawaii." *Forest History Today* Spring/Fall 2011. Weeks Act Centennial Issue (2011): 64-69. Web. 16 Dec. 2016.
- Honolulu Board of Water Supply. "Special Thanks." *Water for Life The History and Future of Water on O'ahu* 22.1 (2008): n. pag. Web. 12 Dec. 2016.
- Ho'okuleana. *Ancient Agricultural Production Intensification*. Digital image. *Ho'okuleana*. N.p., 1 Nov. 2012. Web. 10 Dec. 2016.
- Ho'okuleana. *Coconut Grove and Residence of King Kamehameha V*. Digital image. *Ho'okuleana*. N.p., 26 June 2012. Web. 10 Dec. 2016.
- Hoskins, W. G., and Christopher Taylor. *The Making of the English Landscape*. London: Hodder & Stoughton, 1988. Print.
- HSHK. *Kane and Kaneloa*. Digital image. *Hawaiinuiakea School of Hawaiian Knowledge*. N.p., n.d. Web. 10 Dec. 2016.
- Intergovernmental Panel on Climate Change (IPCC), comp. *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Ed. Thomas F. Stocker, Dahe Qin, Gian-Kasper Plattner, Melinda MB Tignor, Simon K. Allen, Judith Boschung, Alexander Nauels, Yu Xia, Vincent Bex, and Pauline M. Midgley. Cambridge: Cambridge UP, 2014. Print.
- International Union for Conservation of Nature. Ecosystem services diagram. Digital image. *Fresh Water Watch*. N.p., 9 Feb. 2017. Web. 26 Feb. 2017.
- International World History Project. "Sumeria, The City Of Ur." *Sumeria, The City Of Ur*. N.p., n.d. Web. 14 Dec. 2016.
- Jackson, John Brinckerhoff. *Discovering the Vernacular Landscape*. New Haven: Yale UP, 1984. Print.

- Jive'n, Gunila, and Peter J. Larkham. "Sense of Place, Authenticity and Character: A Commentary." *Journal of Urban Design* 8.1 (2003): 67-81. Print.
- Ka Papa Lo'i 'o Kānewai. *Kanewaie*. Digital image. *Welina Manoa*. N.p., n.d. Web. 10 Dec. 2016.
- Kamakau, Samuel Manaiakalani,, Mary Kawena, Pukui, and Dorothy B. Barre re. *Tales and Traditions of the People of Old / Nā Mo'olelo O Ka Po'e Kabiko*. Honolulu: Bishop Museum, 1991. Print.
- Kamehameha Schools. Conceptual ahupua'a. Digital image. *Kumukahi.org*. N.p., n.d. Web. 10 Dec. 2016.
- Kanahele, George. *Waikiki 100 BC to 1990 AD : An Untold Story*. Honolulu: Queen Emma Foundation, 1995. Print.
- Kane, Herb Kawainui. *The Planter*. Digital image. *Island Breath*. N.p., 3 June 2006. Web. 10 Dec. 2016.
- Karamanea, Panita. "Landscape, Memory and Contemporary Design." Ed. Kay Lawrence. *Craft+design Enquiry* 7 (2015): 113-34. Web. 14 Dec. 2016.
- Kira, Hanako. *Kawainui Marsh*. Digital image. *Deviantart*. N.p., 21 Dec. 2011. Web. 10 Dec. 2016.
- Kirch, Patrick Vinton, and Marshall Sahlins. *Anahulu : The Anthropology of History in the Kingdom of Hawaii*. Chicago: U of Chicago, 1992. Print.
- Kirpich, Phillip Z. "Irrigation Mnagement." *Water Encyclopedia: Science and Issues*. N.p., n.d. Web. 16 Dec. 2016.
- Kumukahi.org. Ahupua'a. Digital image. *Kumukahi.org*. N.p., n.d. Web. 10 Dec. 2016.
- Löwenborg, Daniel. "Watersheds as a Method for Reconstructing Regions and Territories in GIS." *Digital Discovery. Exploring New Frontiers In Human Heritage*. N.p.: n.p., 2007. 143-49. Print.
- Last Stand: The Vanishing Hawaiian Forest*. Honolulu, HI: Nature Conservancy of Hawaii, 2003. Print.
- Lautze, Jonathan. *Key Concepts in Water Resource Management: A Review and Critical Evaluation*. London: Routledge, 2014. Print.
- Linen Postcard of Kapi'olani Park C. 1920-40s*. Digital image. *Downwind Productions*. N.p., n.d. Web. 10 Dec. 2016.

- Lum, Cory. Water in the Ala Wai Canal turned brown after heavy rains last week. In a major flood, the canal would overflow into the heart of Waikīkī. Digital image. *Civil Beat*. N.p., 1 Sept. 2015. Web. 10 Dec. 2016.
- Marin County Department of Public Works. "Anatomy of a Watershed." *Marin County Watershed Program*. N.p., n.d. Web. 16 Dec. 2016.
- McHugh, Eileen. *Landscape and Memory: Transformation of an Urban River's Edge*. Thesis. Massachusetts Institute of Technology. Dept. of Architecture, 1998. N.p.: Massachusetts Institute of Technology, 1998. *DSpace@MIT*. Web. 16 Dec. 2016.
- Meinig, D. W., and John Brinckerhoff Jackson. "Fundamentals: Axioms for Reading the Landscape: Some Guides to the American Scene / Peirce F. Lewis." *The Interpretation of Ordinary Landscapes: Geographical Essays*. New York: Oxford UP, 1979. N. pag. Print.
- Merlin, Mark, and Dan VanRavenswaay. "The History of Human Impact on the Genus Santalum in Hawaii." *Proceedings of the Symposium on Sandalwood in the Pacific April 9-11, 1990, Honolulu, Hawaii*. Berkeley: Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1990. 46-84. Web. 16 Dec. 2016.
- Millennium Ecosystem Assessment (Program). *Ecosystems and Human Well-being : Synthesis*. Washington, DC: Island, 2005. Print.
- Minerbi, Luciano. *Ahupua'a*. Digital image. *Ho'okuleana*. N.p., 18 June 2012. Web. 10 Dec. 2016.
- Minerbi, Luciano. "Indigenous Management Models and Protection of the Ahupua'a." *The Ethnic Studies Story : Politics and Social Movements in Hawai'i : Essays in Honor of Marion Kelly*. Ed. Ibrahim G. Aoude and M. Kelly. Vol. 39. Honolulu: Dept. of Sociology, U of Hawai'i at Mānoa, 1999. N. pag. Print. Social Process in Hawaii.
- Minerbi, Luciano. *Indigenous Management Models and Protection of the Ahupua'a* (n.d.): n. pag. Web. 12 Dec. 2016.
- Mississauga. *Stormwater Drainage System*. Digital image. *Stormwater Program*. N.p., n.d. Web. 10 Dec. 2016.
- Mānoa Stream Park Conceptual Plan*. 1976. Mānoa Stream Park Conceptual Plan, Honolulu. *Manoa Stream Park Conceptual Plan*. By Advisory Committee for Manoa Stream Park. Honolulu: n.p., 1976. N. pag. Print.
- Moana Surfrider. *Moana Hotel*. Digital image. *Moana Surfrider History*. N.p., n.d. Web. 10 Dec. 2016.

- Moena Park and Ala Wai*. Digital image. *Waikiki Magazine*. N.p., 3 Jan. 2014. Web. 10 Dec. 2016.
- Mohamoud, Yusuf M., Rajbir S. Parmar, and Anne C. Sigleo. *Modeling the Impacts of Hydromodification on Water Quantity and Quality*. Athens, GA: National Exposure Research Laboratory Ecosystems Research Division, 2009. Web. 16 Dec. 2016.
- "Movement of Water." *Movement of Water*. N.p., n.d. Web. 16 Dec. 2016.
- Mueller-Dombois, Dieter. "The Hawaiian Ahupua'a Land Use System: Its Biological Resource Zones and the Challenge for Silvicultural Restoration." *Biology of Hawaiian Streams and Estuaries : Proceedings of the Symposium on the Biology of Hawaiian Streams and Estuaries : Hilo, Hawai'i, 26-27 April 2005*. Ed. N.L. Evenhuis and J.M. Fitzsimons. N.p.: n.p., n.d. N. pag. Web.
- Mumford, Lewis. "The Natural History of Urbanization." *Man's Role in Changing the Face of the Earth*. Ed. William L. Thomas. N.p.: n.p., n.d. 382-484. *Biblioteca CF+S*. 15 Nov. 2002. Web. 16 Dec. 2016. <<http://habitat.aq.upm.es/boletin/n21/almum.en.html>>.
- Norberg-Schulz, Christian. *Genius Loci: Towards a Phenomenology of Architecture*. New York: Rizzoli, 1980. Print.
- Ongley, Edwin D. *Control of Water Pollution from Agriculture*. Rome: Food and Agriculture Organization of the United Nations (FAO), 1996. Web. 15 Dec. 2016.
- Orr, David W. *Earth in Mind: On Education, Environment, and the Human Prospect*. Washington, DC: Island, 2004. Print.
- Ostan, Aleksander Sasa. "Tierra Agua: Paisaje Dual." *Quaderns D'Arquitectura I Urbanisme* Tierra-Agua.212 (1996): 44-45. Web. 16 Dec. 2016.
- Ostrowski, Jorg-Dietram. *Phenomenology of Water & A Scenario For Downtown Waterfronts*. Thesis. Massachusetts Institute of Technology, 1975. N.p.: n.p., n.d. *Dspace.mit.edu*. Web. 14 Dec. 2016.
- Outdoor Foundation. *Outdoor Recreation Participation Topline Report 2016*. Rep. N.p., 2016. Web. 14 Dec. 2016.
- Paradise of the Pacific. *1929 Paradise of the Pacific Shows off Waikiki with Then-new Aerial Photography*. Digital image. *Honolulu Magazine*. N.p., 25 May 2013. Web. 10 Dec. 2016.
- Pope, Alexander, and Herbert Davis. *Poetical Works*. London; New York: Oxford U.P., 1966. Print.

- Richmond, Elliot. "Forest Hydrology - Building, Effects, Important, Types, Plants, Human." *Water Encyclopedia: Science and Issues*. N.p., n.d. Web. 16 Dec. 2016.
- Robinson, Alexander. Natural stones are used to both create walkways for pedestrians and to help regulate water speeds and levels and various points along the stream. Digital image. *Landscape Performance*. N.p., n.d. Web. 10 Dec. 2016.
- Save the Rainforest. *The Layers of the Rainforest*. Digital image. *Rainforest Rescue*. N.p., n.d. Web. 10 Dec. 2016.
- Shaw, Sylvie, and Andrew Francis. *Deep Blue: Critical Reflections on Nature, Religion and Water*. London: Equinox Pub., 2008. Print.
- Simon, Michelle, Michael Borst, and Thomas O'Connor. *Green Infrastructure for Stormwater Control: Gauging Its Effectiveness with Community Partners, Summary of EPA GI Reports*. Washington, DC: U.S. Environmental Protection Agency, 2015. Web. 16 Dec. 2016.
- Smithsonian Institute. "Rainforests." *Smithsonian Tropical Research Institute*. N.p., n.d. Web. 16 Dec. 2016.
- Stannard, David E. *Before the Horror: The Population of Hawaii on the Eve of Western Contact*. Honolulu, HI: Social Science Research Institute, U of Hawaii, 1989. Print.
- Stannard, David E. *Before the Horror: The Population of Hawai'i on the Eve of Western Contact*. Honolulu, HI: Social Science Research Institute, U of Hawaii, 1989. Print.
- State of Hawaii Department of Agriculture. "History of Agriculture in Hawaii." *Department of Agriculture*. N.p., 31 Jan. 2013. Web. 12 Dec. 2016.
- State of Hawaii Department of Land and Natural Resources (DLNR). "State of Hawaii Conservation District Subzone - Island of Oahu." *Dlnr.hawaii.gov*. N.p., Nov. 2012. Web. 1 Dec. 2016.
- Stobbelaar, Derk Jan, and Bas Pedroli. "Perspectives on Landscape Identity: A Conceptual Challenge." *Landscape Research* 36.3 (2011): 321-39. Print.
- Stone, Charles P., and Stephen J. Anderson. "Introduced Animals in Hawaii's Natural Areas." *Proceedings of the Thirteenth Vertebrate Pest Conference (1988)*. Vertebrate Pest Conference Proceedings, Monterey, California. 1988. 134-40. Web. 16 Dec. 2016.
- Sugarhouse New Year's Eve Fireworks on the Waterfront*. Digital image. *Delaware River Waterfront*. N.p., 1 Dec. 2015. Web. 10 Dec. 2016.
- Susan. *Duke Kahanamoku Memorial Statue*. Digital image. *Flickr*. N.p., 10 Aug. 2012. Web. 10 Dec. 2016.



- Sutrov, Maggie T. *Haloo*. Digital image. *Island Breath*. N.p., 9 Jan. 2008. Web. 10 Dec. 2016.
- SWA. *Lewis Avenue Corridor*. Digital image. *SWA*. N.p., n.d. Web. 10 Dec. 2016.
- SWA. *Sims Bayou Aerial Shot*. Digital image. *SWA*. N.p., n.d. Web. 10 Dec. 2016.
- Townscape, Inc., and Eugene Dashiell. *Ala Wai Watershed Analysis Final Report*. Rep. N.p.: n.p., 2003. Print.
- Turenscape. *Site Plan*. Digital image. *American Society of Landscape Architects*. N.p., n.d. Web. 10 Dec. 2016.
- Turgeon, Andrew. "Rain Forest." *National Geographic Society*. Ed. Caryl-Sue Micalizio. N.p., 11 May 2015. Web. 16 Dec. 2016.
- UNEP. *Cities and Buildings UNEP Initiatives and Projects*. Milan: UNEP-DTIE Sustainable Consumption and Production Branch, n.d. Web. 16 Dec. 2016.
- United Nations. Department of Economic and Social Affairs. Population Division. *The World at Six Billion*. Washington, D.C.: Population Division, Dept. of Economic and Social Affairs, United Nations Secretariat, 1999. Web. 16 Dec. 2016.
- United Nations Department of Economic and Social Affairs/Population Division. *World Urbanization Prospects: The 2014 Revision*. New York: United Nations, 2015. Web. 15 Dec. 2016.
- United Nations. *Patterns of Urban and Rural Population Growth*. New York: United Nations, 1980. PDF.
- University of Arizona. *Irrigation Water Is Shared by Balinese Farming Communities in Ways That Benefit the Community at Large*. Digital image. *UANews*. N.p., 5 Feb. 2013. Web. 10 Dec. 2016.
- USDA Forest Service Southern Research Station. "Fish & Wildlife Research Areas." *USDA*. N.p., n.d. Web. 16 Dec. 2016.
- USEPA. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. Washington, DC: United States Environmental Protection Agency Office of Water, 1993. Web. 16 Dec. 2016.
- USEPA. *National Management Measures to Control Nonpoint Source Pollution from Hydromodification*. Washington, DC: United States Environmental Protection Agency Office of Water, 2015. Web. 16 Dec. 2016.

- USEPA. *National Water Quality Inventory: Report to Congress. 2004 Reporting Cycle*. Washington, DC: United States Environmental Protection Agency Office of Water, 2009. Web. 16 Dec. 2016.
- USEPA. "Sanitary Sewer Overflows (SSOs)." *National Pollutant Discharge Elimination System*. N.p., n.d. Web. 16 Dec. 2016.
- USEPA. "What Is Green Infrastructure?" *Green Infrastructure*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "The Effects of Urbanization on Water Quality: Sewage Overflows." *The USGS Water Science School*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "The Effects of Urbanization on Water Quality: Waterborne Pathogens." *The USGS Water Science School*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "Infiltration - The Water Cycle." *The USGS Water Science School*. N.p., n.d. Web. 16 Jan. 2016.
- USGS. "Non-point Source (NPS) Pollution." *Water Science Glossary of Terms*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "Runoff (surface Water Runoff)." *The USGS Water Science School*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "Transpiration - The Water Cycle." *The USGS Water Science School*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "Wastewater Treatment Water Use." *The USGS Water Science School*. N.p., n.d. Web. 16 Dec. 2016.
- USGS. "What Is a Watershed?" *The USGS Water Science School*. N.p., n.d. Web. 16 Dec. 2016.
- Venenoso, Patrick. Rice terraces of the Philippine Cordilleras. Digital image. *UNESCO*. N.p., n.d. Web. 10 Dec. 2016.
- Weinstock, Michael. *The Architecture of Emergence : The Evolution of Form in Nature and Civilisation*. Chichester, U.K.: Wiley, 2010. Print.
- Weyeneth, Robert R. *Kapiolani Park: A Victorian Landscape of Leisure*. Honolulu, HI: Dept. of Parks and Recreation, City and County of Honolulu, 1991.
- Whipple, William. *Stormwater Management in Urbanizing Areas*. Englewood Cliffs, N.J.: Prentice-Hall, 1983. Print.
- Winter, Thomas C., and N. Earl Spangenberg. "Wetlands - River, Depth, Freshwater, Important, Types, System, Plants, Source, Marine, Oxygen, Human." *Water Encyclopedia: Science and Issues*. N.p., n.d. Web. 16 Dec. 2016.